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PILE FABRICS FOR INSULATION

WADC TECHNICAL REPORT 54-374

PILE FABRICS FOR INSULATION

CHARLES W. LONG

MATERIALS LABORATORY

JUNE 1955

PROJECT No. 7320

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
[illegible] - 17 January 1956

FOREWORD

This report was prepared by the Textiles Branch and was initiated under Project No. 7320, "Air Force Textile Materials", Task No. 73202, "Air Force Clothing Textile Materials", formerly RDO No. 612-13, "Air Force Clothing Textile Materials", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Lt C. W. Long and Lt R. M. Ellis acting as project engineers. Work was initiated as a part of the wool conservation program established by Headquarters, USAF. Materials discussed herein were developed by Goodall Sanford, Inc., Princeton Knitting Mills, and George W. Borg Corp. under USAF contracts AF 33(600)-15961, AF 33(600)-9415 and AF 33(616)-77, respectively. Test data presented are based upon tests conducted at Materials Laboratory, Directorate of Research, Wright Air Development Center.

This report covers work conducted from August 1952 to August 1954.

ABSTRACT

This is a report on pile fabrics made from synthetic fibers, cotton, wool and numerous blends thereof. There were three techniques employed in the construction of the pile fabrics developed under this project: (1) woven cut pile fabrics by Goodall Sanford, Inc., (2) inserted pile, knitted fabrics by George W. Borg Corporation and (3) napped and/or brushed pile, knitted fabrics by Princeton Knitting Mills, Inc. All the samples developed were compared to the standard wool pile fabric made according to requirements of AF Specification MIL-C-5563. Each sample was tested for warmth and compression characteristics to determine the effect, if any, of varying thicknesses, blends, and constructions. It was observed that the type fiber has little effect on the warmth of a pile fabric; however, Orlon, Dacron and Dynel consistently appear slightly better. Results show that possibly a double thickness of a relatively thin pile fabric should deserve consideration. Also included in this report are the results of a study on the mathematical relationship between the warmth of a fabric and the physical properties of the fabric.

PUBLICATION REVIEW

.s report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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INTRODUCTION

This project was a result of the wool conservation program. Currently a wool pile fabric with a woven cotton base cloth is being used extensively by the Air Force as an insulation fabric in flight garments, cold weather gear, etc. The objective of this investigation was to develop an insulation fabric of synthetic fibers or fibers other than wool, that would be equal to or an improvement over the presently used wool pile fabric. First attempts included the development of a honeycomb weave fabric. This type fabric contains a considerable amount of air space which is a requirement of a good insulating fabric; however, for proper warmth an increase in thickness would be necessary which, in turn, would increase the weight to the extent that this type fabric would not be practical. Consideration was also given to a freize type fabric which, in many cases, also presents a weight problem. Pile fabrics, on the other hand, can be light weight, of required thickness, and low cost.

PILE FABRICS FOR INSULATION

Although the basic requirement of an insulation fabric is to produce proper warmth for the wearer, there are other requirements that must be taken into consideration. They are wearability, tendency to "mat" after being compressed, shrinkage to laundering and sewability.

Because the insulation fabric is employed between layers of other fabrics, there is no requirement for abrasion resistance; however, it is required to have good wearability. Wearability is a general requirement which includes physical properties not usually called out as a definite requirement in addition to the basic requirements. An insulation fabric that has good wear properties will exhibit nearly the same physical properties, after being put into service for prolonged lengths of time, as it initially exhibited.

To be considered in evaluating the suitability of a pile fabric is the tendency to "mat" or "set" after being compressed. It would be very undesirable for a pile fabric to remain at the compressed thickness after a load is relieved. The thickness, and consequently the porosity (per cent air), which are the determining warmth properties of a fabric, would be reduced. Therefore, the fabric should be resilient, or should return to the original thickness after being compressed.

Minimum shrinkage in cleaning and good sewability are obvious requirements. Some garments which employ the use of an insulation fabric will be laundered, while others may be dry cleaned. The sewability characteristics of the insulation fabric should not necessitate the use of any equipment other than conventional types used in fabrication of clothing.

The results of tests conducted on all fabrics are given in Tables 1, 2 and 3. Compression versus thickness curves and porosity versus thickness curves are presented in Appendix I to further illustrate these characteristics of each fabric. Figures 23, 24 and 25 of Appendix I are bar graphs which show the weight-to-warmth ratio, no load porosity, and compressibility, respectively, for each fabric.

Woven, cut pile, fabrics; Manufacturer: Goodall-Sanford, Inc.

These fabrics were constructed like the standard wool pile fabric described in Specification MIL-C-5563. The weights and thicknesses of all of these samples were nearly the same, ranging in thickness from .242 inch to .365 inch, and in weight from 15.75 ounces per square yard to 18.86 ounces per square yard.

Advantages of these fabrics are that they possess good compression and resilience properties. Shrinkage can be held to a minimum due to the construction, and there will be no fabrication problem.

Table 1

Woven Cut Pile Fabrics

Sample Number	Blend: Pile	Blend: Base	Fabric Thickness Inches	Compressibility Percent	Porosity: No Load	Porosity: Full Load 176 gm/in^2	Weight oz/yd^2	Conductance *	Weight To Warmth Ratio **
458	100% Dynel	100% Dynel	.263	46.4	94.4	89.8	16.14	3.35	54.1
460	100% Dacron	100% Dacron	.311	42.8	95.5	92.1	16.60	2.37	39.3
462	100% Orlon	100% Orlon	.251	39.7	93.9	89.8	15.75	2.91	45.8
464	75% Dynel 25% Vicara	100% Cotton	.253	51.8	93.6	86.8	17.82	3.69	65.8
466	100% Dynel	100% Cotton	.242	47.1	94.0	88.6	16.94	3.19	54.2
468	75% Dacron 25% Dynel	100% Cotton	.347	48.6	95.3	90.9	17.42	2.42	42.2
470	75% Dacron 25% Vicara	100% Cotton	.311	47.9	94.9	90.1	17.79	2.18	38.8
472	50% Dacron 50% Dynel	100% Cotton	.321	39.9	94.9	91.6	18.44	2.61	48.0
474	75% Orlon 25% Vicara	100% Cotton	.282	42.4	93.5	88.7	16.82	3.03	50.8
476	50% Orlon 50% Dynel	100% Cotton	.319	50.6	92.5	84.7	17.45	2.88	50.2
478	50% Orlon 50% Acrilan	100% Cotton	.263	35.8	91.9	87.3	17.61	2.73	48.1
480	100% Wool	100% Cotton	.365	43.9	95.4	91.9	18.86	1.77	33.3
482	100% Orlon	100% Cotton	.272	38.3	93.7	89.7	17.58	3.09	54.3
484	50% Orlon 50% Dacron	100% Cotton	.296	36.1	94.4	91.2	17.44	2.64	46.0
486	100% Dacron	100% Cotton	.281	37.2	94.8	91.6	17.63	2.36	41.7
MIL-C-5563	100% Wool	100% Cotton	.434	46.5	96.6	93.7	17.22	1.58	27.21

* Conductance = calories per second per square meter per $^{\circ}$ Centigrade temperature differential.

** Weight to Warmth Ratio = required weight of fabric to produce a conductance of 1.00

Table 2

Knitted - Inserted Pile Fabric

Sample Number	Blend: Pile	Blend: Base	Fabric Thickness Inches	Compressibility Percent	Porosity: No Load	Porosity: Full Load 176 gm/in²	Weight oz/yd²	Conductance *	Weight To Warmth Ratio **
ML 1	50% Dacron 50% Acrilan	100% Cotton	.382	61.7	95.8	89.1	18.54	1.77	32.8
ML 3	100% Dynel	100% Cotton	.436	39.9	96.6	93.3	18.29	2.24	40.9
ML 4	100% Orlon	100% Cotton	.504	48.0	96.5	93.3	16.85	1.87	31.5
ML 5	100% Dacron	100% Cotton	.532	66.1	97.2	91.8	16.21	1.87	30.4
ML 6	100% Dynel	100% Cotton	.432	65.4	95.5	92.3	19.22	1.79	34.4
ML 7	100% Nylon	100% Cotton	.506	58.1	96.3	91.2	18.92	1.58	29.9
ML 8	100% Wool	100% Cotton	.544	62.1	97.1	92.3	19.45	1.66	32.3
ML 9	100% Nylon	100% Cotton	.450	61.0	96.9	92.1	12.30	2.18	26.8
ML 10	100% Dynel	100% Cotton	.390	59.0	96.8	92.0	11.74	2.18	25.6
MIL-C-5563	100% Wool	100% Cotton	.434	46.5	96.6	93.7	17.22	1.58	27.2

* Conductance = Calories per second per square meter per ° Centigrade temperature differential.
** Weight To Warmth Ratio = Required weight of fabric to produce a conductance of 1.00

Table 3

Knitted and Napped Pile Fabric

Sample Number	Blend: Pile	Blend: Base	Fabric Thickness Inches	Compressibility Percent	Porosity: No Load	Porosity: Full Load 176 gr/in²	Weight oz/yd²	Conductance *	Weight To Warmth Ratio **
1	100% Orlon	100% Orlon	.259	42.6	96.2	93.5	8.32	2.76	22.9
2	100% Dacron	100% Dacron	.246	43.3	93.6	88.7	15.31	2.97	45.5
3	100% Nylon	100% Nylon	.250	44.8	93.0	87.4	14.91	3.02	45.0
4	100% Orlon	100% Orlon	.274	48.9	95.8	91.8	10.03	2.88	28.7
5	100% Orlon	100% Orlon	.218	48.6	95.2	90.6	9.21	3.80	34.9
6	100% Orlon	100% Orlon	.288	46.6	96.4	93.3	9.06	2.65	24.0
7	100% Dacron	100% Dacron	.278	36.3	95.9	93.4	11.95	2.46	29.4
8	100% Dacron	100% Dacron	.265	36.8	96.9	93.7	10.86	2.51	27.2
9	100% Dacron	100% Dacron	.298	43.6	95.5	91.9	13.97	2.51	34.6
1' ***	100% Orlon	100% Orlon	.518	42.6	96.2	93.5	16.64	1.41	23.4
MIL-C-5563	100% Wool	100% Cotton	.434	46.5	96.6	93.7	17.22	1.58	27.21

* Conductance = Calories per second per square meter per ° Centigrade temperature differential.
** Weight To Warmth Ratio = Required weight of fabric to produce a conductance of 1.00.
*** Double thickness of No. 1 Sample.

Disadvantages of this type of fabric are that nearly all of the samples were as heavy or heavier than the wool control sample and the porosities were generally low which contributes to the high weight-to-warmth ratio. The cost of this type fabric would be somewhat higher than a similar knitted fabric.

Knitted, inserted pile, fabric; Manufacturer: George W. Borg Corp.

These fabrics were made by inserting the pile from a sliver form into the base fabric while on the knitting machine. The machine pulls the fibers into the base fabric and anchors them so they can not be easily pulled out. The thicknesses and weights of these samples were all nearly the same except for ML 9 and ML 10 which were considerably lighter and not quite as thick.

Advantages of this type of fabric are high porosities, low conductance, and relatively low cost.

Disadvantages include high weight and therefore high weight-to-warmth ratio. ML 9 and ML 10 being lighter weight had lower weight-to-warmth ratios; however, the compressibility of these fabrics was high. Also the shrinkage in laundering was high.

Knitted, napped pile fabric; Manufacturer: Princeton Knitting Mills, Inc.

These fabrics were knitted with a terry loop on the face which was napped to give a smooth pile effect. These fabrics were light weight and not very thick.

Advantages of this type fabric are light weight, high porosity, good strength, and low cost.

Disadvantages are not outstanding.

One fabric of the knitted, inserted pile type, ML 10, and one of the knitted napped pile type, No. 1, were considered to possess the best qualities of the samples submitted. Sufficient yardage of the samples was requested of the contractor for further test and evaluation. Complete physical properties of these samples are presented in Table 4. Consideration has been given to a double thickness of Sample No. 1. There is a somewhat greater warmth obtained from a double thickness of a fabric than a single fabric of the same total thickness.* In this case the total weight would be less than that of the standard sample, the thickness slightly more, and the warmth afforded would be greater. The porosity is high enough for proper warmth, as shown in Table 3, and yet, low enough to eliminate any insulation loss due to convection air currents. The disadvantage of this particular material is flammability. Such a fabric made of Orlon is very flammable.

* American Wool Handbook, Second Edition, 1948, p. 162.

Table 4

COMPLETE PHYSICAL PROPERTIES OF SAMPLES 1 AND ML 10

Properties	No. 1	ML 10
Weight oz/yd^2	6.99	10.78
Breaking strength - lbs/in		
Wales	48.8	40.0
Courses	52.0	35.0
Bursting strength - lbs		
Ball burst	98.4	60.0
Thickness - ins	.321	.274
MEK Extractable matter - %	1.19	0.74 *
Shrinkage in laundering		
100°F - %		
Wales	1.21	7.34
Courses	.33	+1.71
212°F - %		
Wales	16.71	1.14
Courses	3.92	19.21
Thickness after laundering - ins.		
100°F	.315	.280
212°F	.180	.274
Compressibility - %		
Original	53.76	64.05
After 100°F laundering	55.42	58.57
After 212°F laundering	55.68	45.25
Weight to warmth ratio	17.76	44.35

* CCl_4 used instead of MEK

Summary

It can be concluded that synthetic pile fabrics are equally as warm as wool pile fabrics and in most cases can be made lighter. In the event that the present supply of wool were to become critical or that the demand for wool exceeded the availability, a suitable synthetic pile fabric could be produced economically to replace the presently used wool pile fabric. However, it would not be advantageous to utilize synthetics unless such a condition should arise, because of the flammability characteristics of such synthetic fabrics. Generally, synthetic pile fabrics will melt or burn very rapidly, in contrast to wool pile fabrics which neither melt nor exhibit a fast rate of burning.

DISCUSSION OF TEST METHODS

THERMAL TRANSMISSION

The apparatus used was a Central Scientific Company thermal conductance device, Figure 1. This device does not take into consideration the unit thickness of the test sample, but rather the total thickness. When the sample had been positioned for test it was compressed to a pressure of 23 grams per square inch. By use of the line rheostat, the galvanometer was then adjusted slightly above full scale reading. As heat was transmitted through the fabric, the galvanometer needle deflected downward until it reached the full scale mark, at which time the test was started. Galvanometer readings were taken in increments of 5 minutes for 30 minutes and recorded.

The galvanometer readings were plotted on a semilog scale, Y axis, against "time" on the rectangular scale, X axis. From this curve the Central Scientific Company tester gave the conductance corresponding to the angle of depression. The conductance represents the rate of heat transmission without consideration of fabric thickness. If the conductance is multiplied by the sample weight in ounces per square yard, the result is the weight-to-warmth ratio, which is defined as the weight of the material necessary to produce a conductance of 1.00.

COMPRESSIBILITY AND POROSITY

Compressibility - The apparatus used was a cylindrical glass tube 1.5 inches in diameter with a fixed rule attached, which was graduated in 1/100 inches. See Figure 2. For each test, five sample thicknesses, 1.5 inches in diameter were placed in the graduated cylinder. Thin pieces of paper of the same diameter as the samples were placed between each sample to prevent them from intermeshing at the plane of contact. Known weights were applied in increments of 16 grams per square inch from 0 load to a load of 176 grams per square inch from which the compression curves in Appendix I were plotted.

FIGURE I

CENTRAL SCIENTIFIC COMPANY THERMAL CONDUCTANCE TESTER

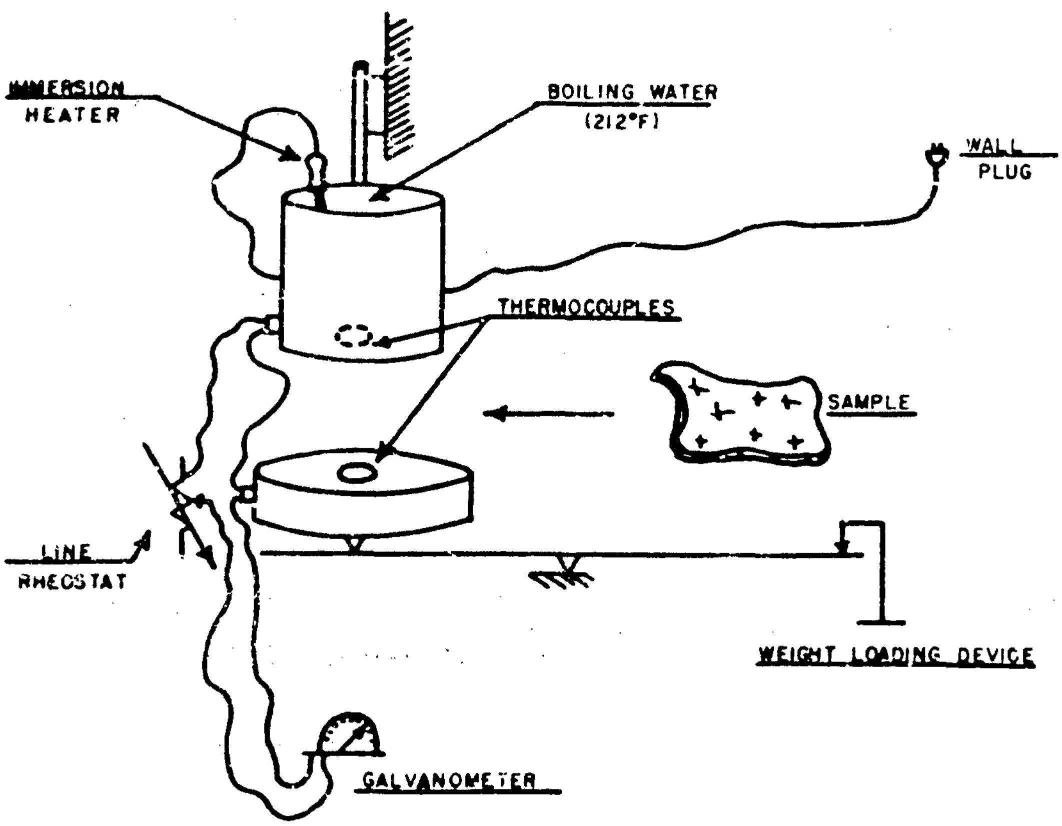
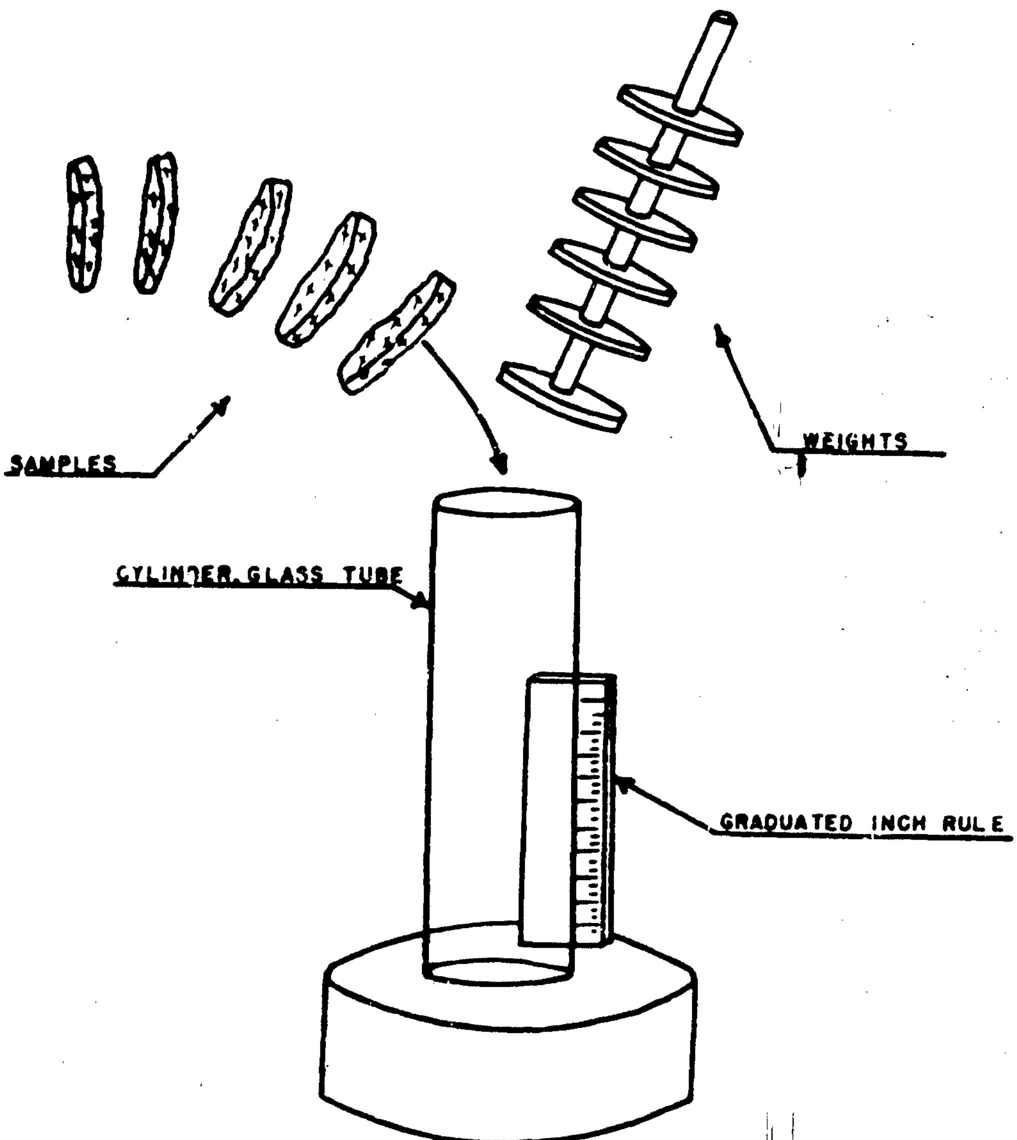


FIGURE 2

COMPRESSIBILITY TESTER



The compressibility was determined as follows:

a. $\% \text{ Compressibility} = \frac{(\text{no load thickness} - \text{full load thickness})}{\text{No load thickness}} \times 100$

It is to be noted that the above thickness is based on one sample thickness. The thickness taken from the scale during test was reduced by the thickness of the separators and divided by 5, the number of samples tested.

The porosity, percent air by volume, was calculated for each fabric thickness obtained in determination of compressibility. Porosity versus thickness curves were plotted and are presented in Appendix I. The porosity was calculated as follows:

b. $\% F = \frac{.00338 \times W \times 100}{tD_f}$

c. $P = 100\% - \% F$

Where: .00338 converts ounces per square yard to grams per square centimeter
$\% F$ = percent fiber by volume
W = fabric weight in ounces per square yard
t = fabric thickness in centimeters
D_f = fiber density in grams per cubic centimeter
P = porosity - percent air by volume

In determining the compressibility by the above outlined method there is one source of error that could very possibly affect the results. The samples tend to spread out as weight is applied on top of them. This causes the surface around the circumference of the samples to be pressed against the walls of the glass cylinder, which exerts a frictional force against downward movement as additional weights are applied. This source of error is evident; however, it is small.

CALCULATION OF CONDUCTANCE

The total warmth of a fabric is determined by the heat transmission properties of that fabric. A "warm" fabric acts as an insulator, and therefore resists the transmission of heat.

Total insulation would be a perfect vacuum. For practical applications, dead air space is the best insulator, or from a textile standpoint, the fabric with the highest porosity. The percent air in a fabric by volume is called porosity. Over a wide range of pile fabrics, including napped, inserted, and cut pile, the results of many tests show that the porosities of these fabrics, unloaded, are in excess of 90% and less than 98%. Results presented in Tables 1, 2 and 3 show that the porosities are all nearly the

ense. It has also been established that the type of fiber has very little effect on the thermal insulation of a fabric. The little effect which might be due to the type of fiber is either too small to measure or masked by other factors which have a much greater effect. Therefore, the most important properties of an insulating pile fabric are the compressional resistance of the fabric and the tendency of the fabric to return to its original thickness after repeated cycles of loading and unloading, assuming that the initial thickness can be controlled.

There is a definite relationship between the warmth of a fabric and its degree of porosity (porosity x thickness). The most practical measurement of warmth is by determination of the thermal conductance, C, which is defined as the amount of heat to pass through a given medium of certain area over a definite length of time with a given temperature difference (calories per second per square centimeter, per 1°C. Temperature differential). The assumption will be made that the conductance of a fabric is proportional to the degree of porosity of the fabric. That is

$$\text{(a)} \quad C' \propto tP$$

where t is the fabric thickness in centimeters and P is the porosity of the fabric. Theoretically, if the thickness is increased, the conductance will decrease. Likewise, if the porosity is increased, the conductance will decrease and therefore

$$\text{(b)} \quad C' = \frac{b}{tP}$$

where b is an equation constant. There will always be a certain amount of air in a fabric, and P will be greater than 0. Keeping this in mind, let t approach 0, and C' will approach infinity. Then let t approach infinity and C' will approach 0. Theoretically, then, equation (b) satifies the conditions of a rectangular hyperbola, the equation of which is

$$\text{(c)} \quad y = \frac{k}{x}$$

where $y = C'$, $k = b$, and $x = tP$.

If both sides of equation (b) are multiplied by tP, then

$$\text{(d)} \quad b = C' Pt$$

t may be measured directly in centimeters. P may be determined from equations (b) and (c) from the discussion of test methods. To determine C, many analytical measurements were made on a Central Scientific Company thermal conductance device with fabrics of different structure, weight and thickness. From these test results an average b was determined from equation (d). From 15 fabrics the average b was 1.54 and therefore,

$$\text{(e)} \quad C' = \frac{1.54}{tP}$$

The basic heat law for any material states that $Ct = K$; where K is the thermal conductivity of the material in cal/sec/cm/cm^2/°C. If K of a fabric is multiplied by the porosity, percent air, in the fabric, the result is the thermal conductivity of air, and therefore $K_{air} = 1.54 = b$.

Actual tests have been conducted to determine the conductance of air on the Central Scientific Company thermal conductance device with a measured air space of 1 cm. The conductance of air was found to be 1.47 cal/cm^2/sec/°C. If t = 1 in the basic heat law, C = K, the thermal conductivity of air would be 1.47 cal/sec/cm/cm^2/°C.

The data in Table 5 give the physical properties of 15 fabrics tested which include the conductance obtained by test C and the calculated conductance obtained from equation (e), C'. Table 6 gives the numerical coefficient of correlation based on a perfect correlation factor of 1.0.

The calculated conductance, C', appears to correlate quite well with the conductance, C, obtained by test. Figure 3 shows the relationship of the tested conductance to the degree of porosity. However, there are several sources of error possible to affect the results. Examples are machine error, error in reading the machine, inaccurate loading and slight variation in room conditions. Probably the most likely source of error in calculating C' is taking the sample thickness. As previously stated, C was based on a fabric thickness corresponding to a load of 23 gm/in^2, and that thickness was not actually recorded. Since it was necessary to know this thickness to calculate C' so both C and C' would be based on the same thickness, the thickness corresponding to a load of 23 gm/in^2 was taken from compression curves similar to those in Appendix I.

From the data in Table 6, the results show there is better correlation between C and C' in the range of higher porosities. This can be explained due to the fact that equation (e) does not take in consideration the thermal characteristics of the fibrous material. In the range of higher porosities with, for example, 6% fiber by volume, the amount of fiber has an extremely small effect on heat transmission. However, in the case of felt where there is 26% fiber, the heat transmission is affected and equation (e) does not apply with as great a degree of accuracy. If the limiting factors of equation (e) are taken to the extreme where P approaches 0, the conductance would increase to an infinite maximum, which in no case would ever be true. All materials exhibit some resistance to heat transmission. In a nonporous material the heat transmission characteristics can not be based on the amount of air, but on the thermal properties of the material. In the case of fabrics it would be highly complicated to consider the effect of the fibrous material in determining conductance. In such case, factors requiring consideration would be conductivity of the fibrous material, area of fiber in contact with the source of heat, and the arrangement of the fibers. Still, equation (e) will hold true with a negligible degree of error for fabrics with porosities in excess of about 35%.

Table 5
Physical Properties of Fifteen Fabrics

Designation	Type Sample	Fiber Density gr/cm³	Weight oz/yd²	Thickness cm	Porosity %	Degree of Porosity*	Conductance (tested) C**	Conductance (cal) C'	C ***
1	Honeycomb Cloth	1.32	15.8	.482	91.5	.441	3.38	3.50	1.44
2	Std Wool Cut Pile	1.41	17.2	.930	95.6	.891	1.58	1.73	1.39
3	Velour	1.32	19.8	.279	81.8	.228	5.97	6.76	1.44
4	Spun Nylon	1.14	15.9	.711	93.4	.664	2.54	2.32	1.67
5	Napped Pile No. 1	1.17	8.3	.556	95.7	.532	2.76	2.89	1.47
6	Napped Pile No. 5	1.17	9.2	.432	93.9	.406	3.80	3.79	1.54
7	Napped Pile No. 7	1.38	11.9	.574	94.9	.544	2.46	2.83	1.34
8	Cut Pile, No. 460	1.38	16.6	.668	93.5	.626	2.37	2.46	1.48
9	Cut Pile, No. 458	1.31	15.1	.537	92.3	.496	3.35	3.21	1.66
10	Cut Pile, No. 464	1.30	17.5	.528	91.3	.473	3.59	3.26	1.75
11	Cut Pile, No. 468	1.36	17.4	.652	93.4	.608	2.42	2.54	1.47
12	Inserted Pile No. ML 4	1.17	16.9	.942	94.8	.892	1.87	1.73	1.66
13	Inserted Pile No. ML 5	1.43	16.2	.984	96.1	.946	1.87	1.64	1.77
14	Inserted Pile No. ML 7	1.26	18.9	1.025	94.8	.973	1.58	1.58	1.54
15	Wool Felt	1.32	64.5	.635	74.0	.468	2.38	3.29	1.25

* Porosity times Thickness/100
** $cal/sec/cm^2/°C$
*** Equation constant = Conductance, C, times degree of porosity

Table 6
Equation Terms

Sample Designation	X_1	X_2	X_1^2	X_2^2	X_1X_2
1	3.50	3.38	12.20	11.40	11.82
2	1.73	1.63	2.98	2.66	2.82
3	6.76	5.97	45.50	35.60	40.40
4	2.32	2.54	5.38	6.43	5.88
5	2.89	2.76	8.35	7.60	7.97
6	3.79	3.80	14.15	14.40	14.39
7	2.83	2.46	8.00	6.03	6.96
8	2.46	2.37	6.03	5.61	5.83
9	3.11	3.35	9.64	11.20	10.41
10	3.26	3.69	10.61	13.60	12.02
11	2.54	2.42	6.45	5.85	6.14
12	1.73	1.87	2.99	3.50	3.23
13	1.64	1.87	2.69	3.50	3.07
14	1.58	1.58	2.50	2.50	2.48
15	3.29	2.38	10.80	5.65	7.83
Total	43.43	42.07	148.27	135.53	141.25

X_1 = Calculated conductances C'; which is to be estimated

X_2 = Conductances by test C

N = Number of measurements

ρ = Coefficient of correlation

When the values from Table 6 are substituted in the following equation,

$$\rho = \frac{N\Sigma X_1X_2 - (\Sigma X_1)(\Sigma X_2)}{\sqrt{[N\Sigma X_1^2 - (\Sigma X_1)^2][N\Sigma X_2^2 - (\Sigma X_2)^2]}}$$

the coefficient of correlation,

ρ = .977

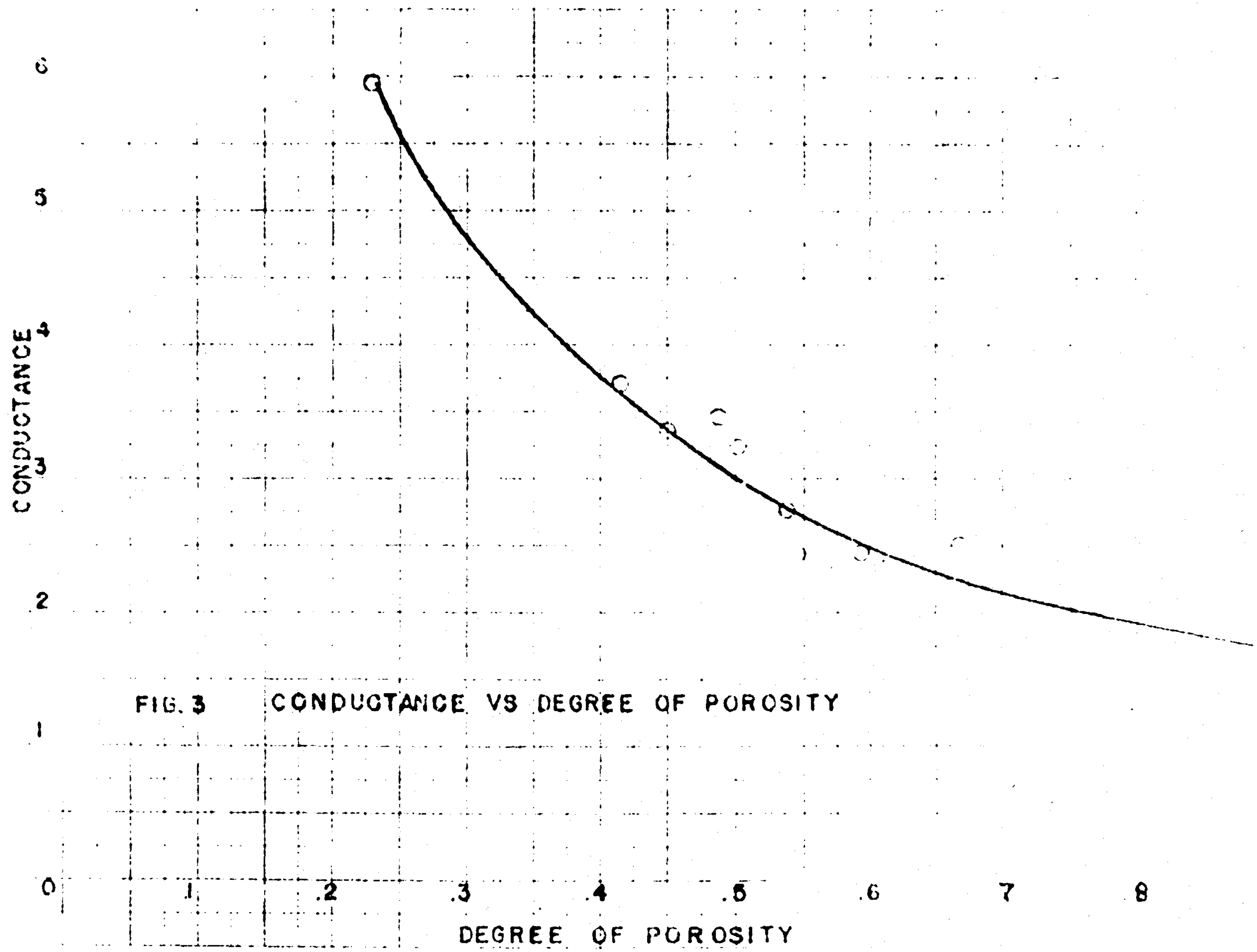


FIG. 3 CONDUCTANCE VS DEGREE OF POROSITY

BIBLIOGRAPHY

Sommer, H. The Hygienic Properties of Cloth Textiles Series Report No. 30, The German Woolen and Worsted Industry in World War II, Part II, Section J, pp. 86-92

Von Bergen - Mauersberger, Thermal Qualities of Wool, American Wool Handbook, Second Edition, pp. 158-168

APPENDIX I

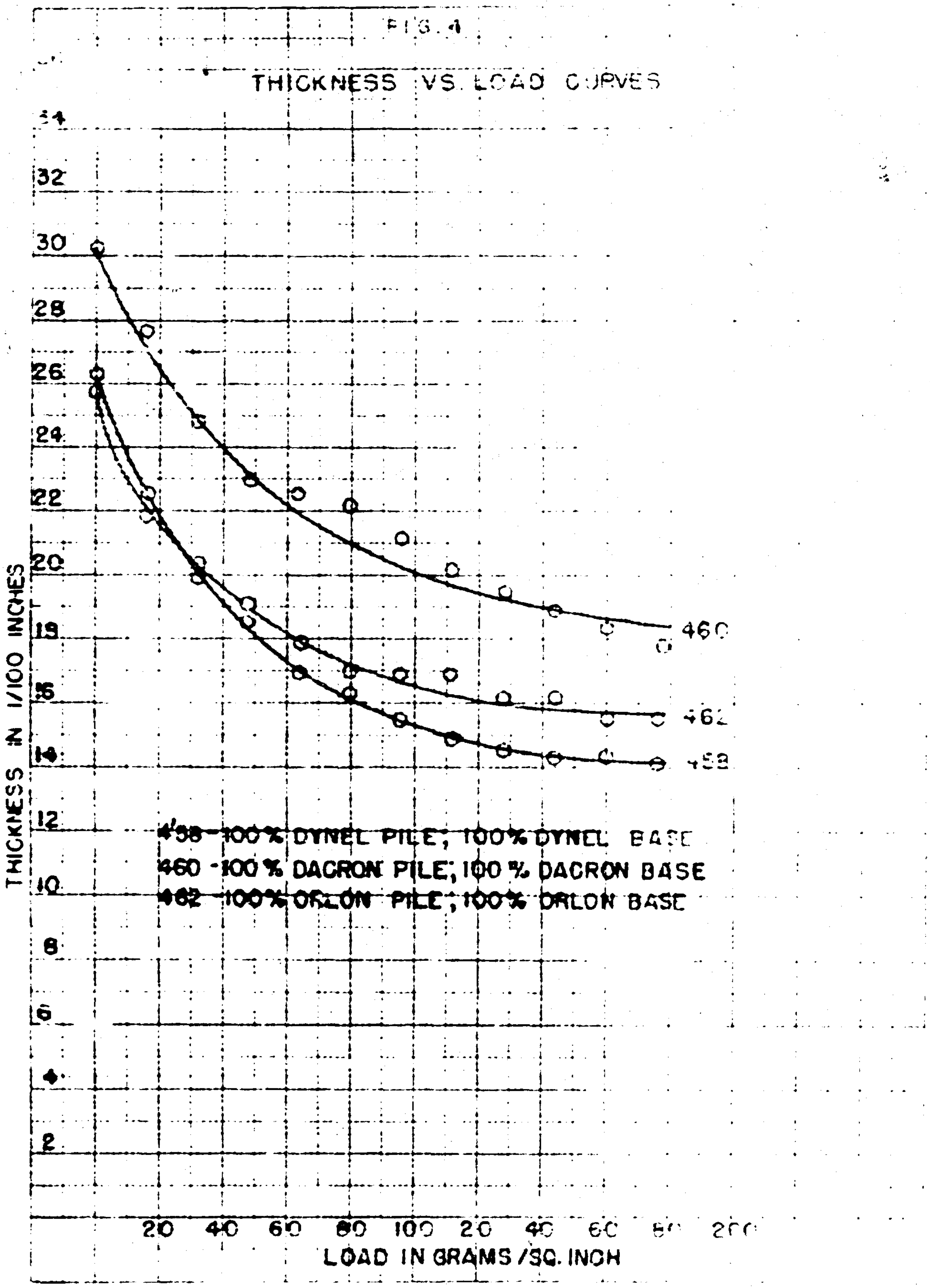


FIG. 4

THICKNESS VS. LOAD CURVES

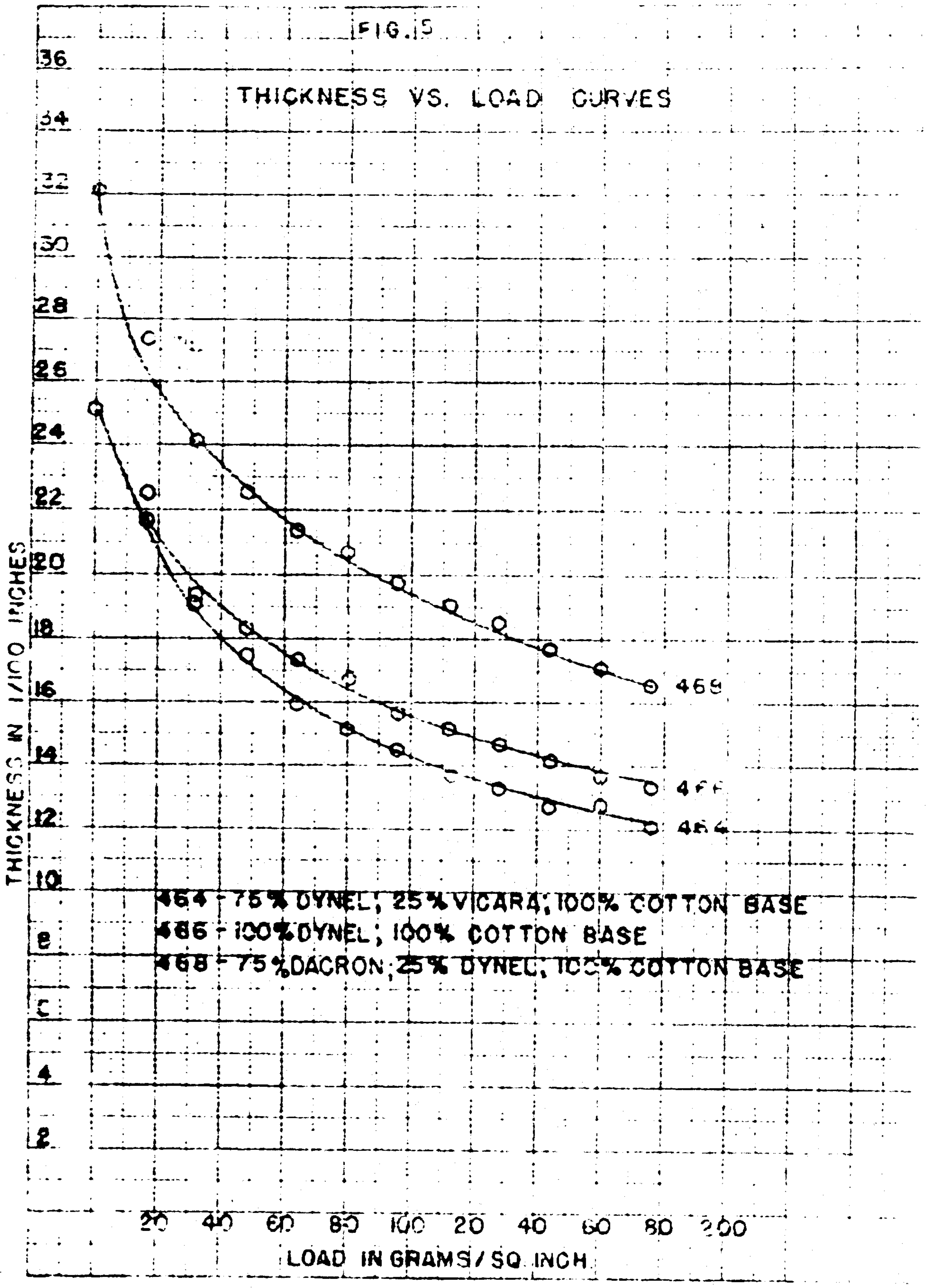


FIG. 15
THICKNESS VS. LOAD CURVES
THICKNESS IN 1/100 INCHES
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
468
466
464
464 - 75% DYNEL, 25% VICARA, 100% COTTON BASE
466 - 100% DYNEL, 100% COTTON BASE
468 - 75% DACRON, 25% DYNEL, 100% COTTON BASE
20
40
60
80
100
20
40
60
80
200
LOAD IN GRAMS/SQ INCH

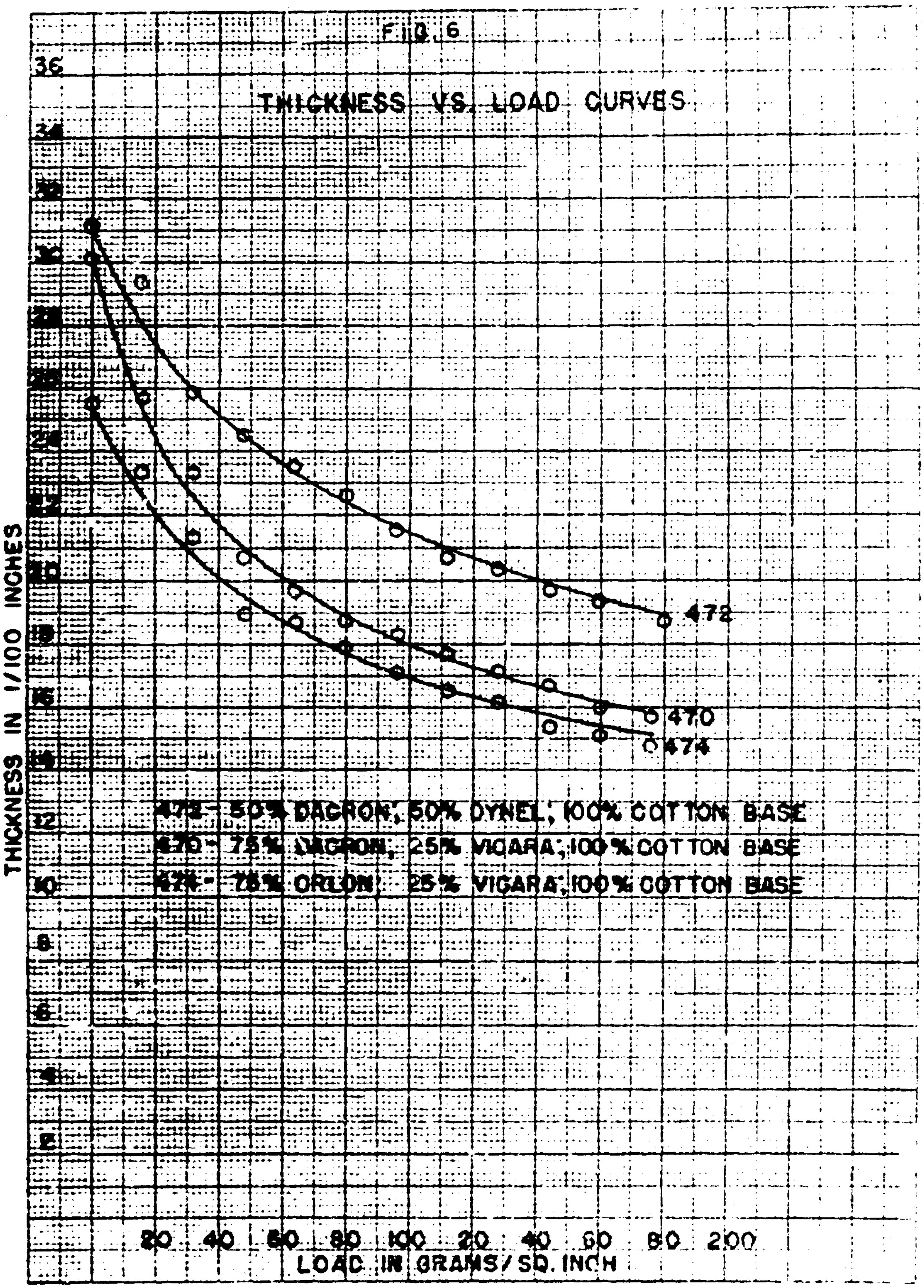


FIG. 6
THICKNESS VS. LOAD CURVES
THICKNESS IN 1/100 INCHES
LOAD IN GRAMS / SQ. INCH
36
10
20 40 60 80 100 20 40 60 80 200
472
470
474
472 - 50% DACRON, 50% DYNEL, 100% COTTON BASE
470 - 75% DACRON, 25% VICARA, 100% COTTON BASE
474 - 75% ORLON, 25% VICARA, 100% COTTON BASE

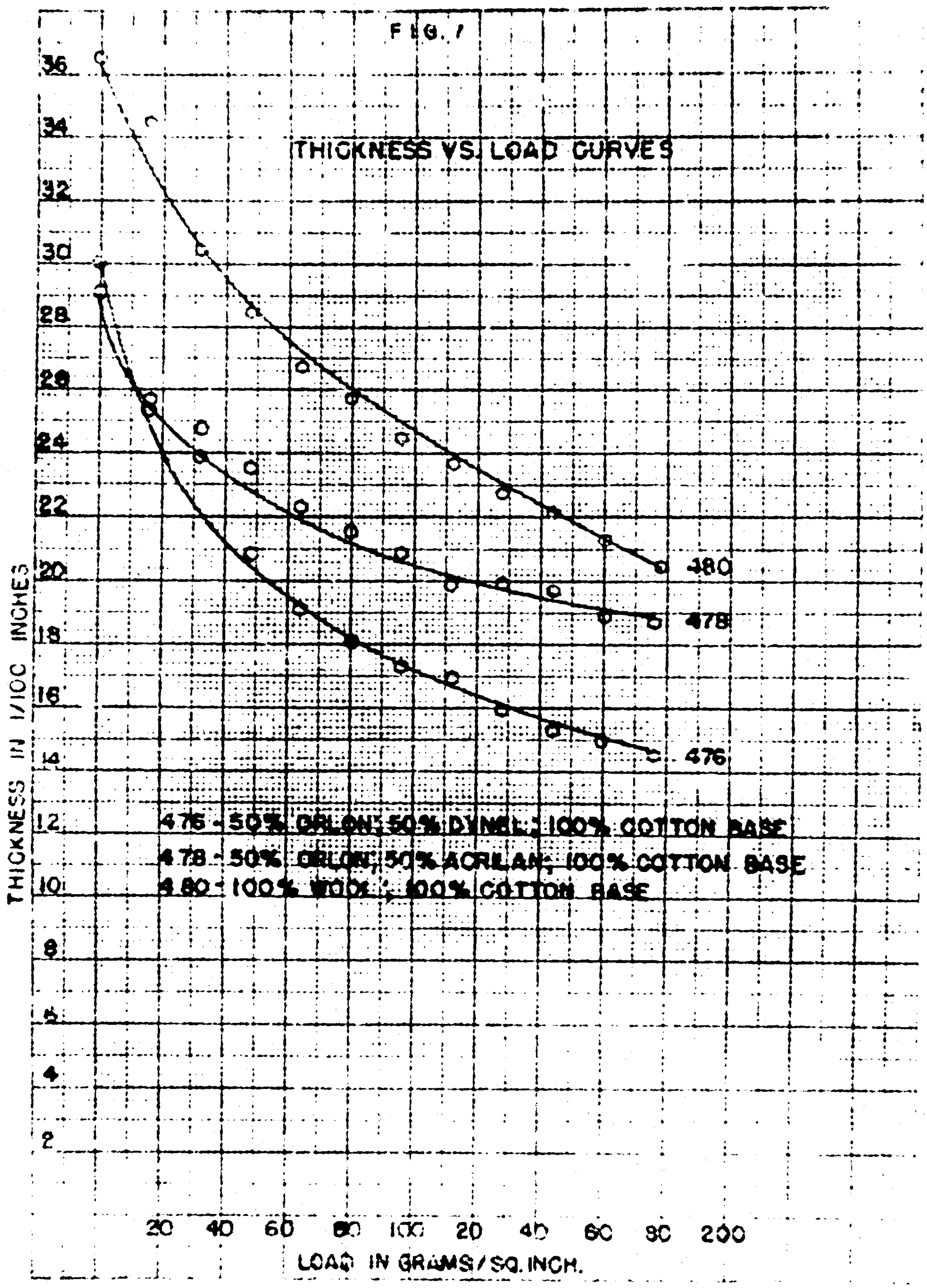


FIG. 1
THICKNESS VS. LOAD CURVES
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
THICKNESS IN 1/100 INCHES
480
478
476
476 - 50% ORLON; 50% DYNEL; 100% COTTON BASE
478 - 50% ORLON; 50% ACRILAN; 100% COTTON BASE
480 - 100% WOOL; 100% COTTON BASE
20 40 60 80 100 20 40 60 80 200
LOAD IN GRAMS/SQ. INCH.

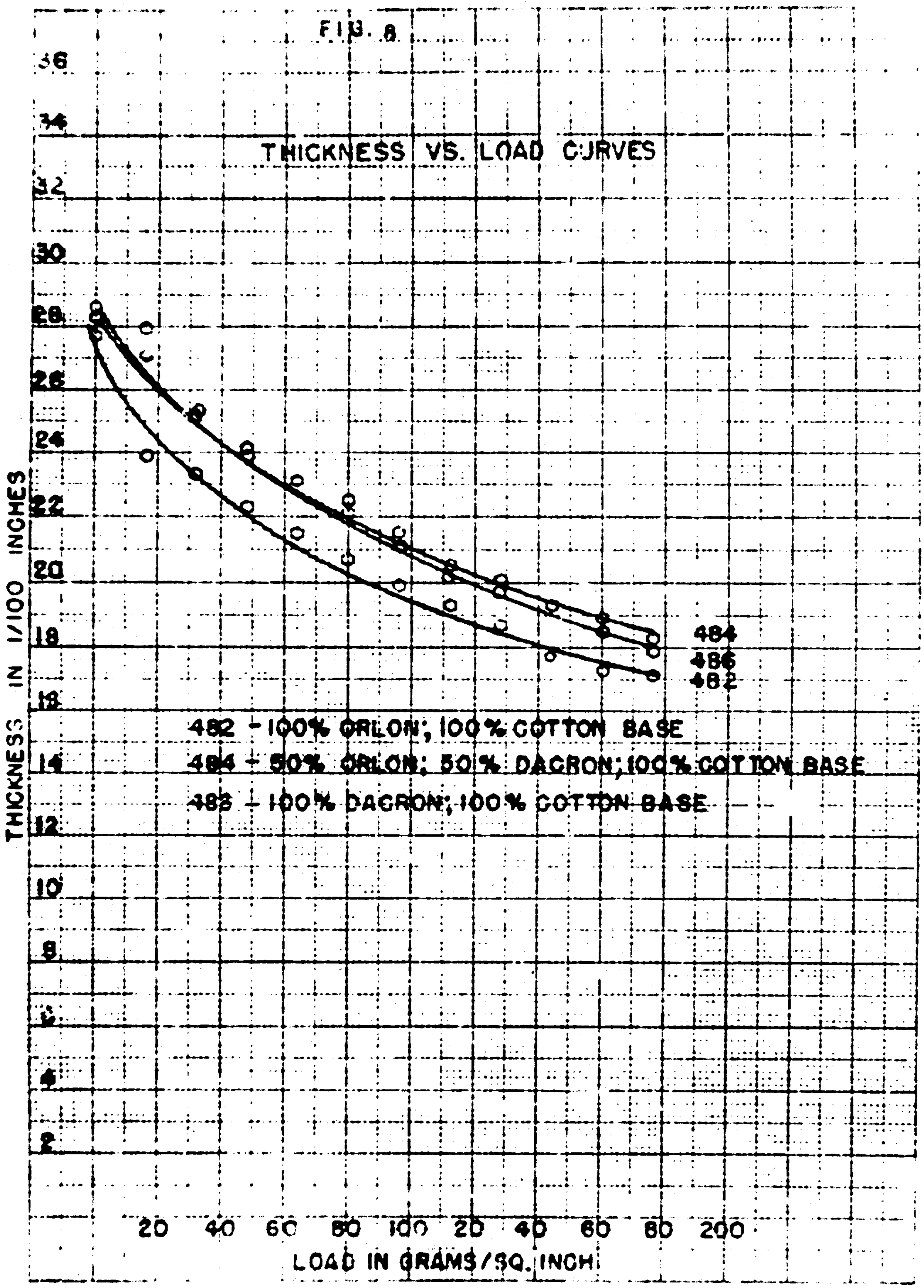
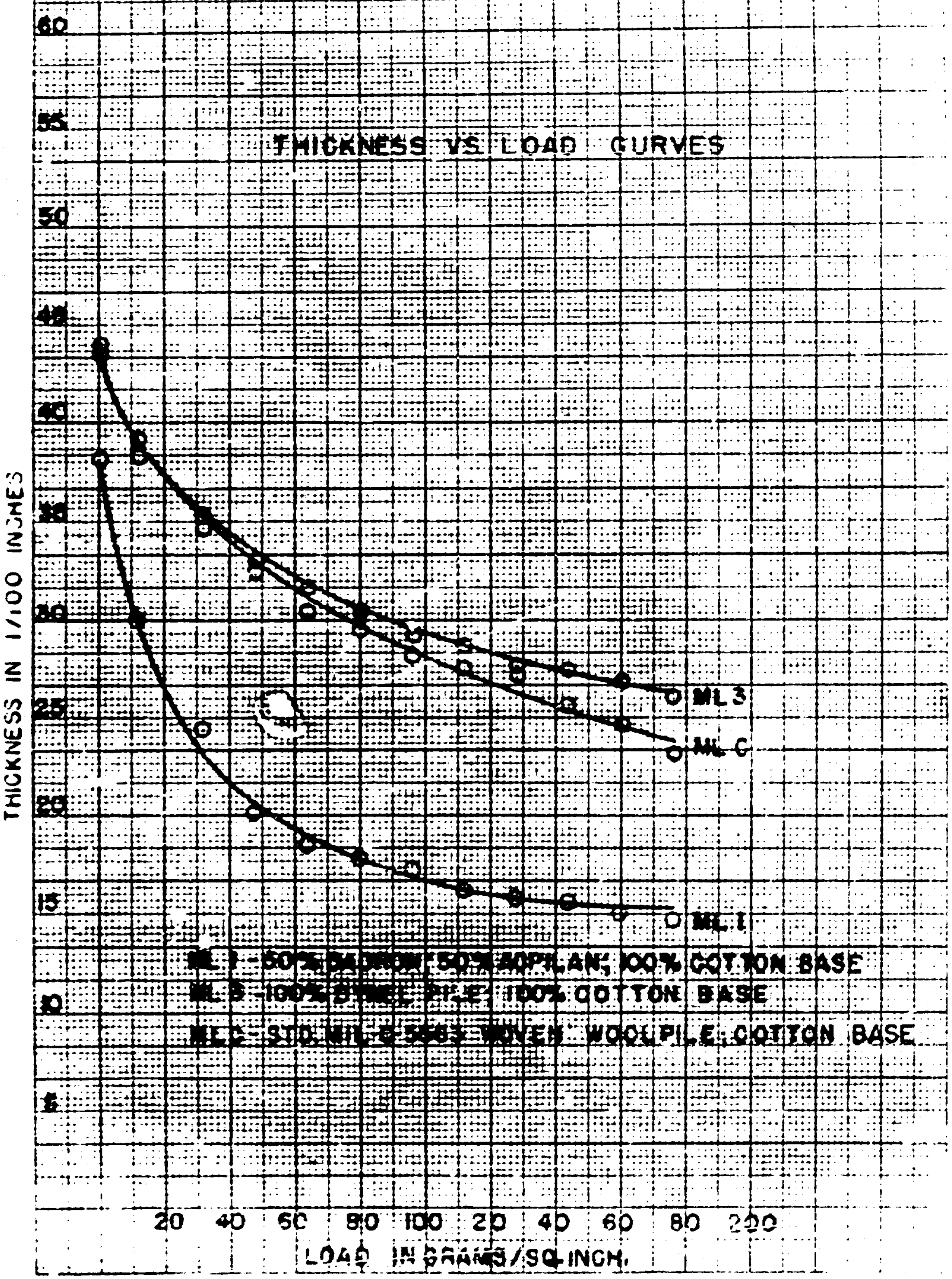


FIG. 8
THICKNESS VS. LOAD CURVES
THICKNESS IN 1/100 INCHES
LOAD IN GRAMS/SQ. INCH
484
486
482
482 - 100% ORLON; 100% COTTON BASE
484 - 50% ORLON; 50% DACRON; 100% COTTON BASE
486 - 100% DACRON; 100% COTTON BASE

FIG. 9


THICKNESS VS LOAD CURVES
THICKNESS IN 1/100 INCHES
LOAD IN GRAMS/SQ.INCH
ML3
ML C
ML 1
100% COTTON BASE
100% COTTON BASE
WOOLPILE COTTON BASE
60
55
50
45
40
35
30
25
20
15
10
5
20
40
60
80
100
20
40
60
80
200

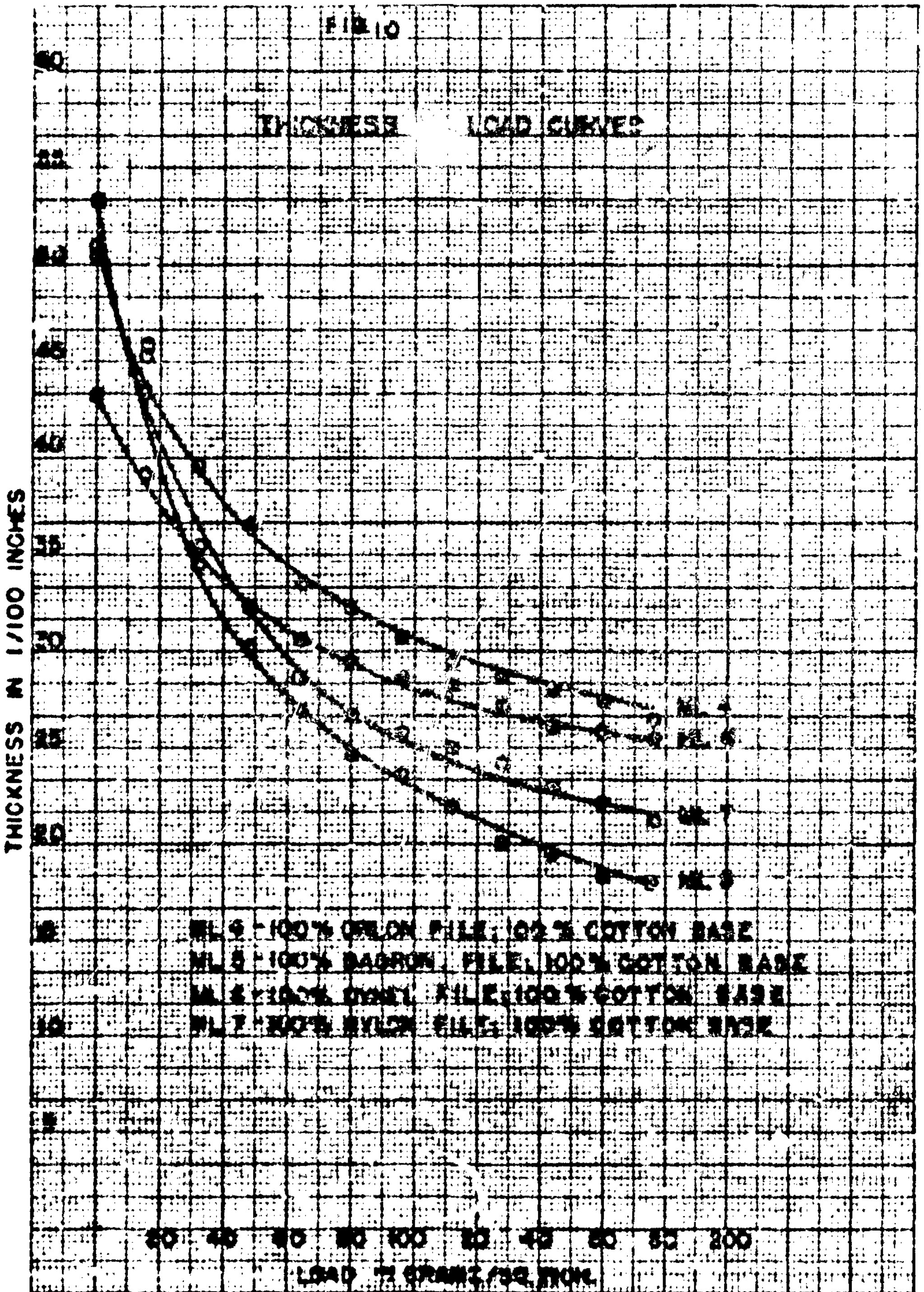
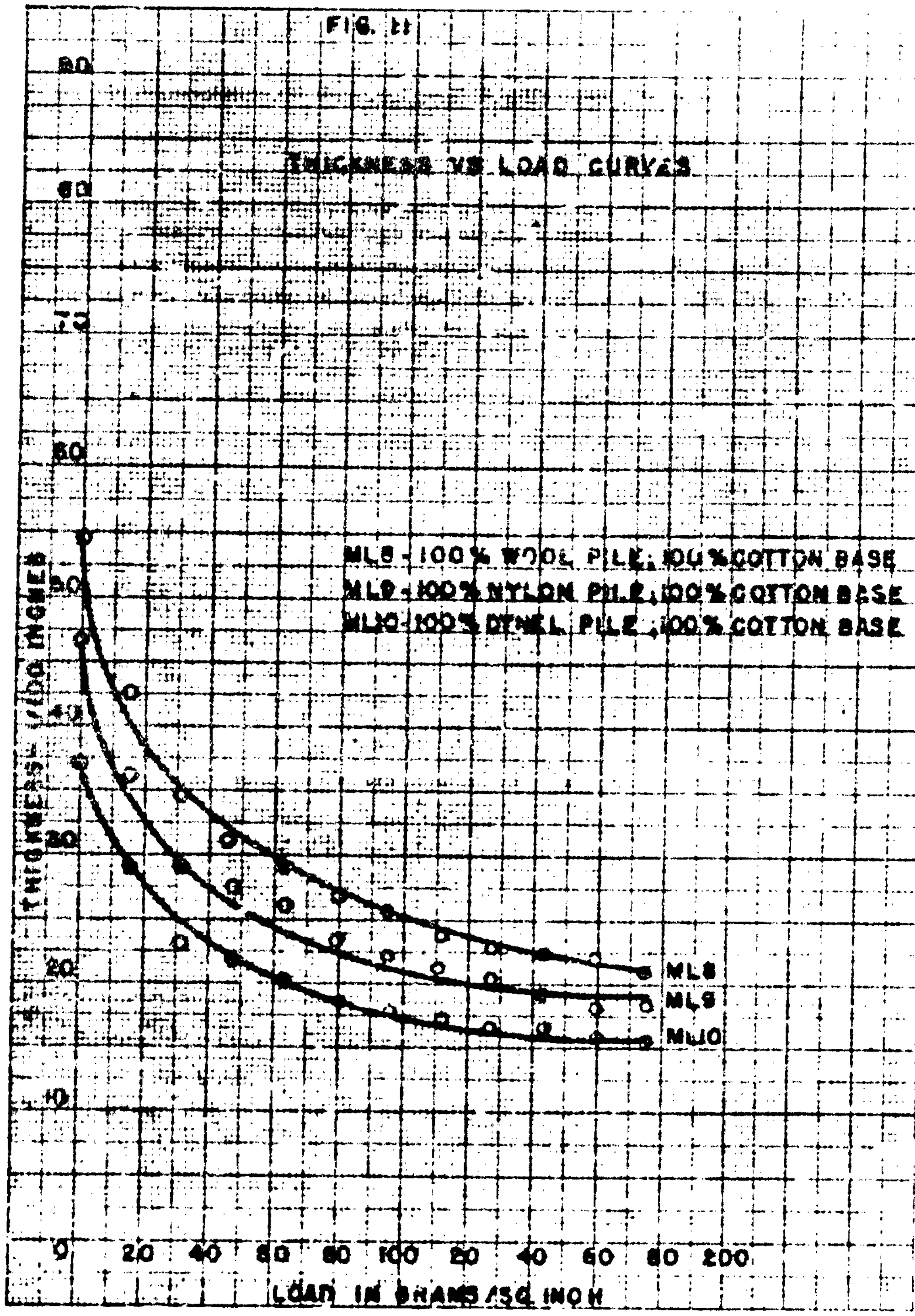


FIG. 10

FIG. 11


THICKNESS VS LOAD CURVES
ML8 - 100% WOOL PILE, 100% COTTON BASE
ML9 - 100% NYLON PILE, 100% COTTON BASE
ML10 - 100% DYNEL PILE, 100% COTTON BASE
ML8
ML9
ML10
THICKNESS - 1/100 INCHES
LOAD IN GRAMS/SQ INCH
0
10
20
30
40
50
60
70
80
20
40
60
80
100
20
40
60
80
200

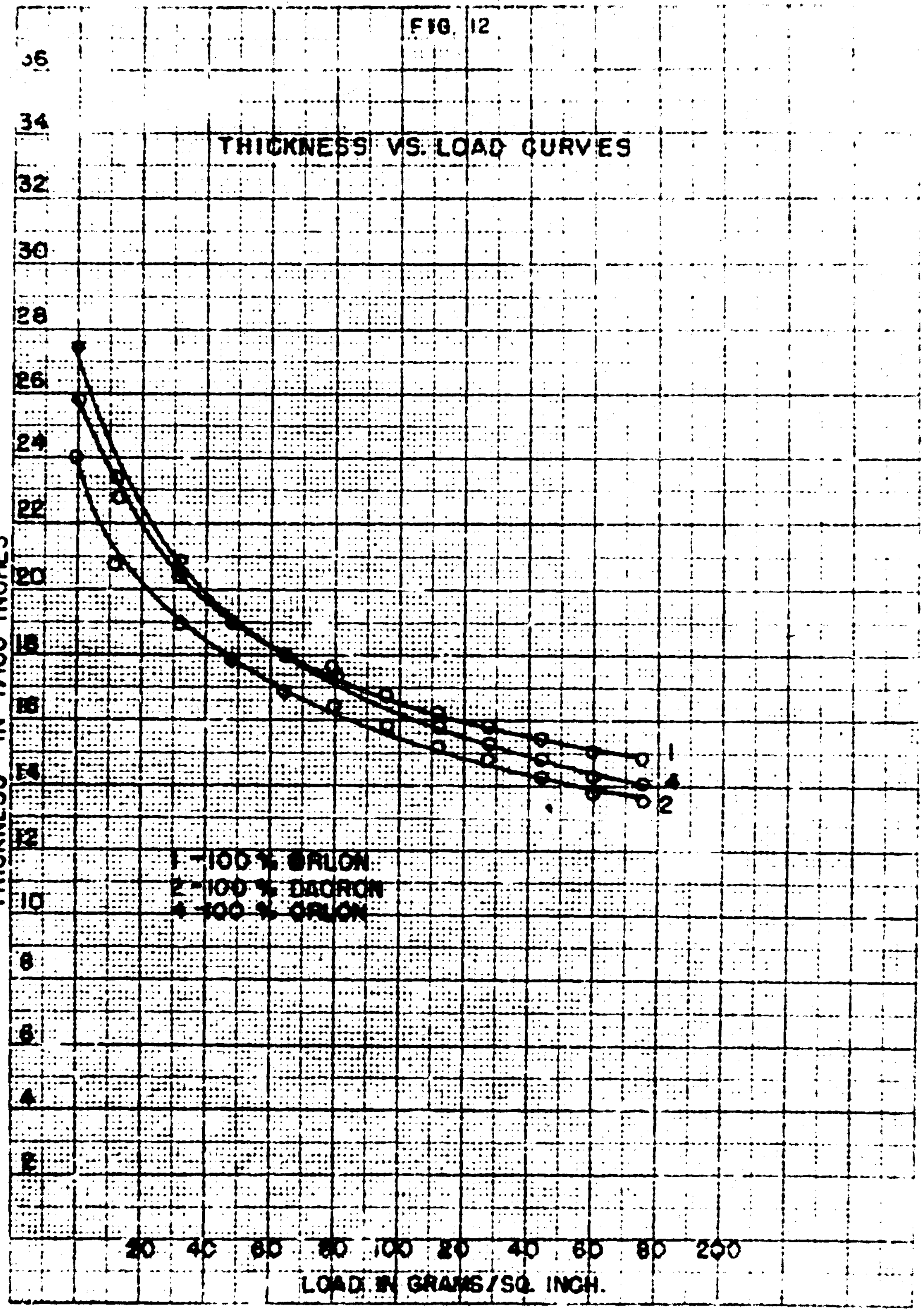


FIG. 12
THICKNESS VS. LOAD CURVES
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
THICKNESS IN 1/100 INCHES
1 -100 % ORLON
2 -100 % DACRON
4 -100 % ORLON
1
4
2
20
40
60
80
100
20
40
60
80
200
LOAD IN GRAMS/SQ. INCH.

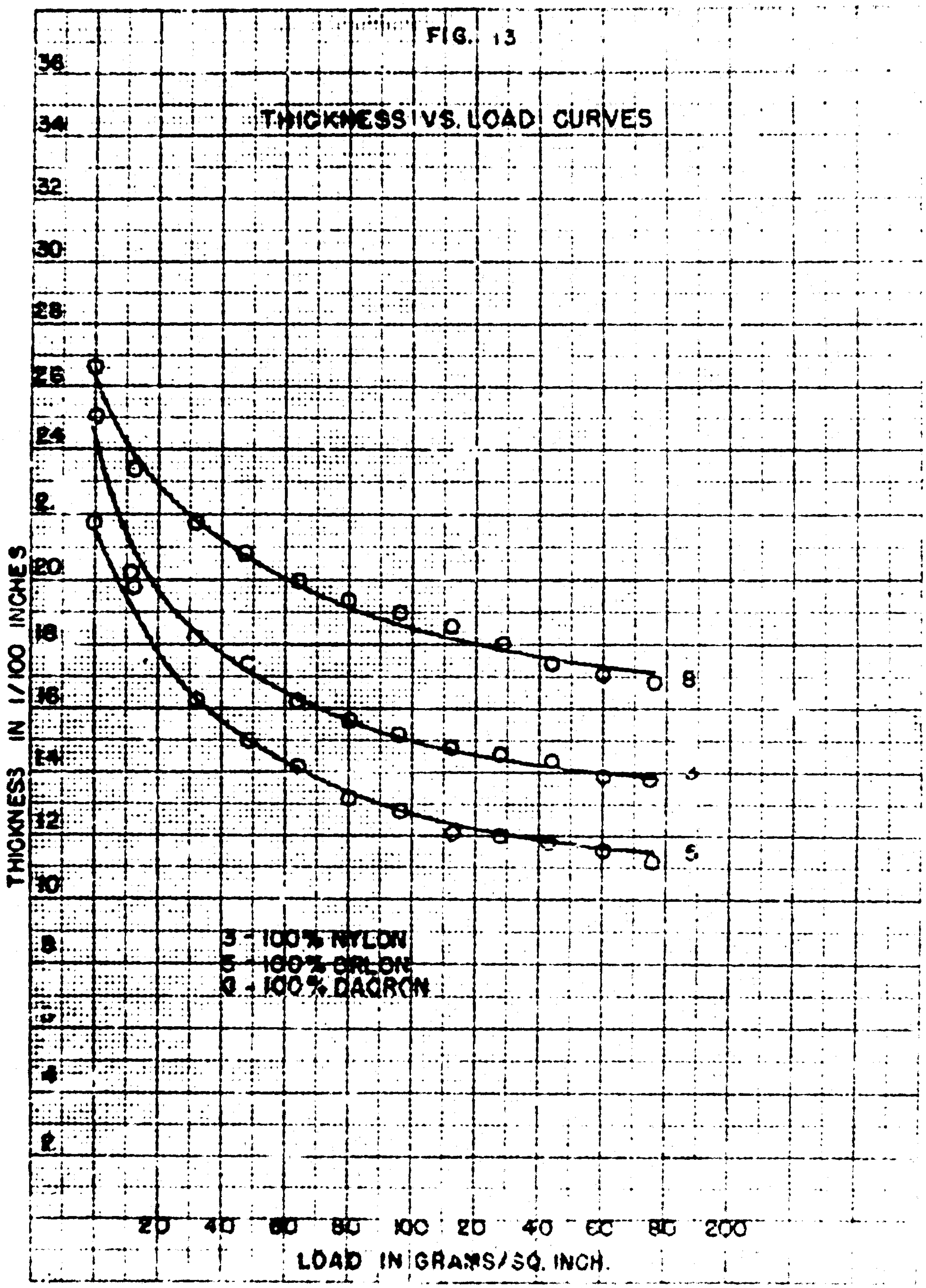


FIG. 13
THICKNESS VS. LOAD CURVES
THICKNESS IN 1/100 INCHES
LOAD IN GRAMS/SQ. INCH.
3 - 100% NYLON
5 - 100% ORLON
8 - 100% DACRON

FIG. 14

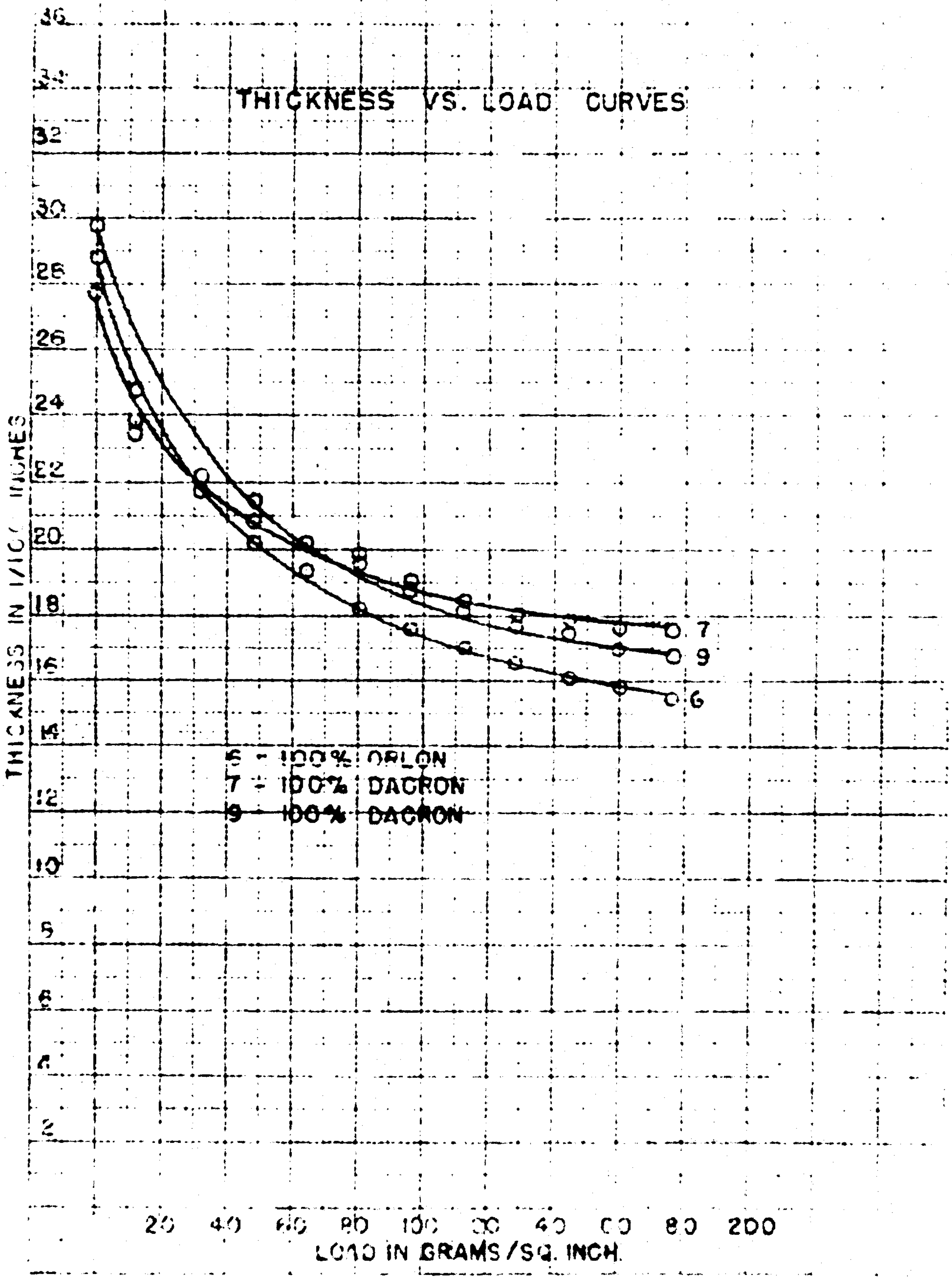

THICKNESS VS. LOAD CURVES
THICKNESS IN 1/1000 INCHES
LOAD IN GRAMS / SQ. INCH
6 - 100% ORLON
7 - 100% DACRON
9 - 100% DACRON
7
9
6
200

FIG.15 POROSITY VS. THICKNESS CURVES

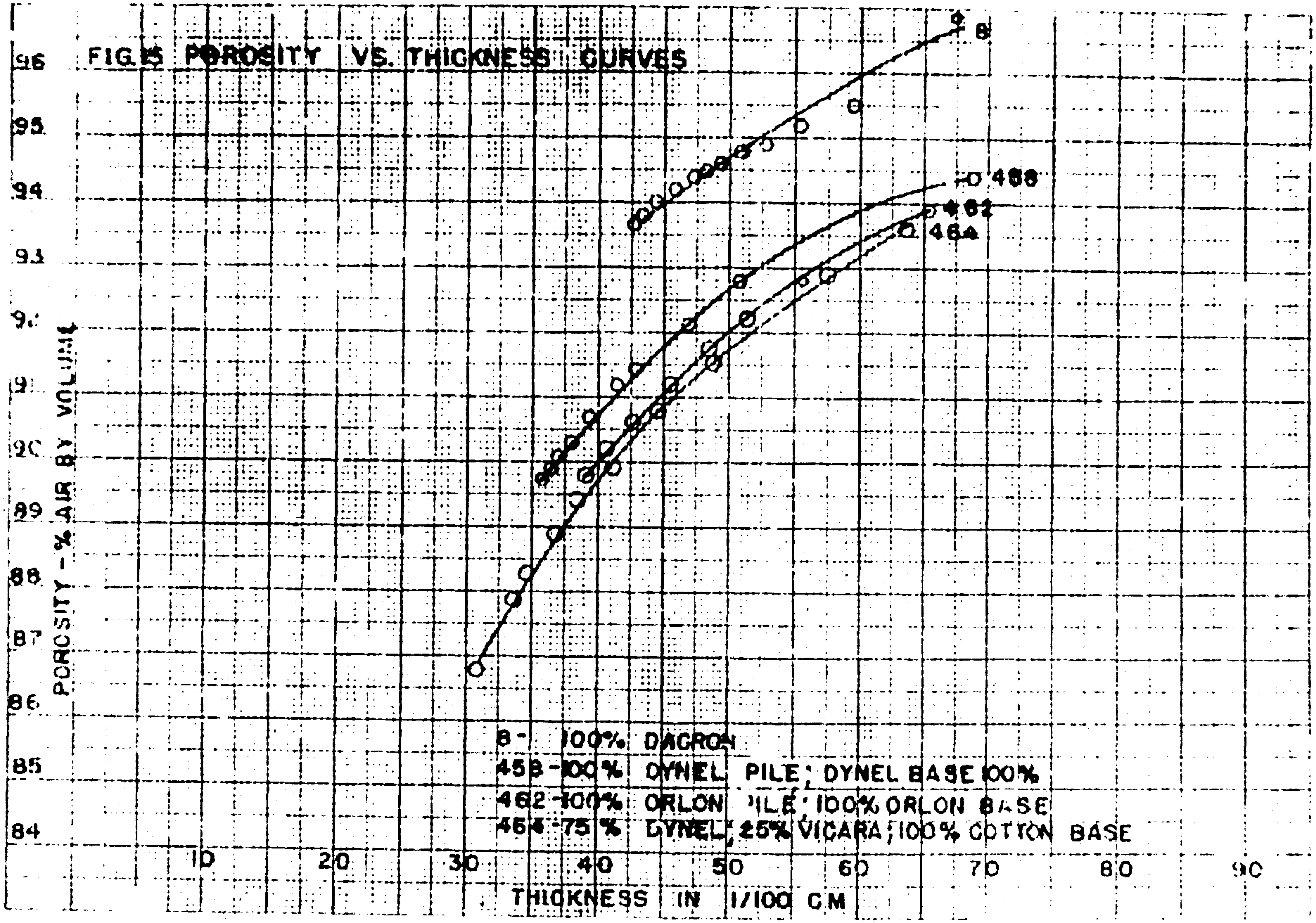


FIG. 16 POROSITY VS. THICKNESS CURVES

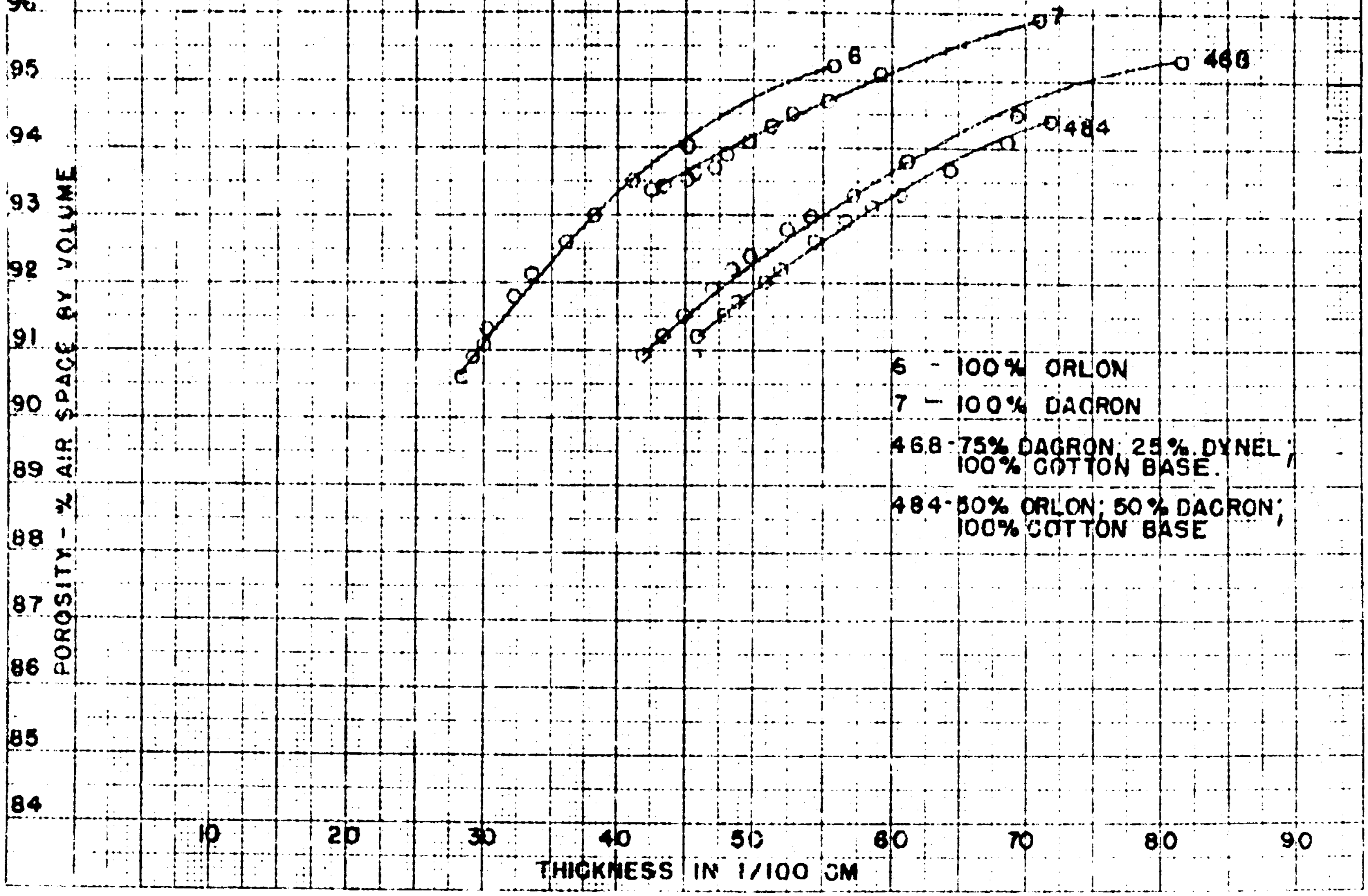
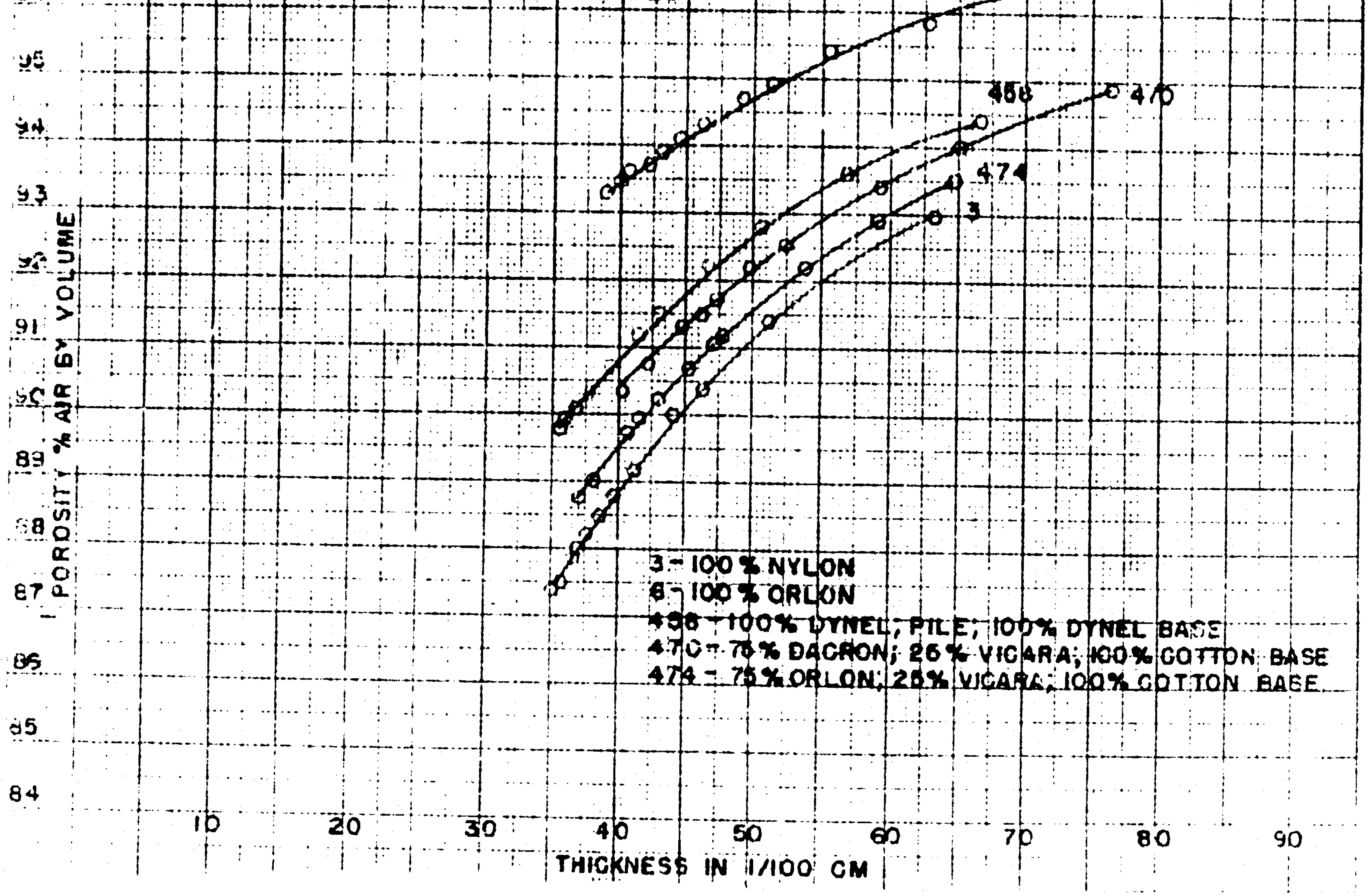
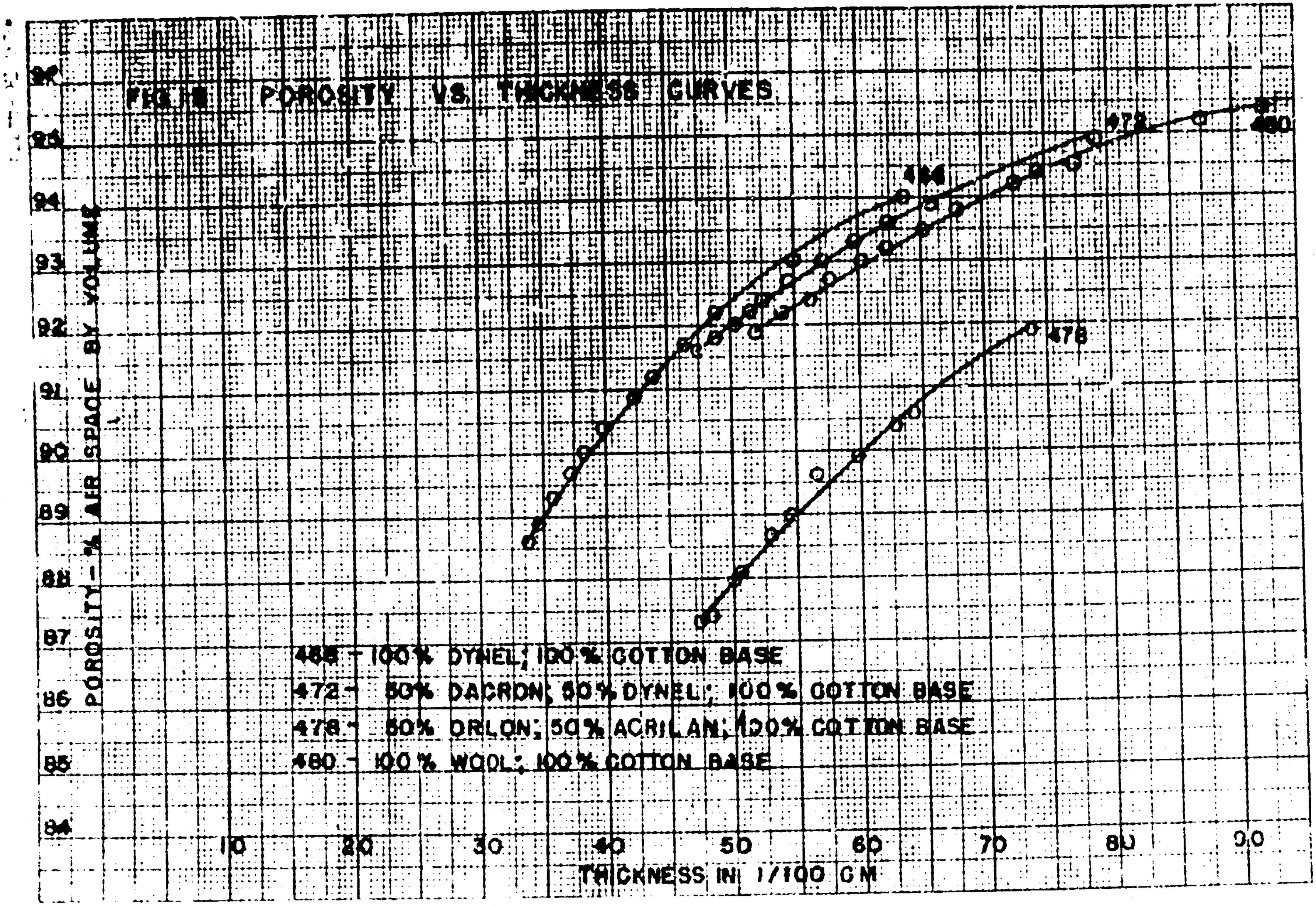


FIG. 17 POROSITY VS. THICKNESS CURVES




POROSITY VS. THICKNESS CURVES
472
480
478
POROSITY – % AIR SPACE BY VOLUME
84
85
86
87
88
89
90
91
92
93
94
95
10
20
30
40
50
60
70
80
90
THICKNESS IN 1/100 CM
100% DYNEL; 100% COTTON BASE
472 – 50% DACRON; 50% DYNEL; 100% COTTON BASE
478 – 50% ORLON; 50% ACRILAN; 100% COTTON BASE
480 – 100% WOOL; 100% COTTON BASE

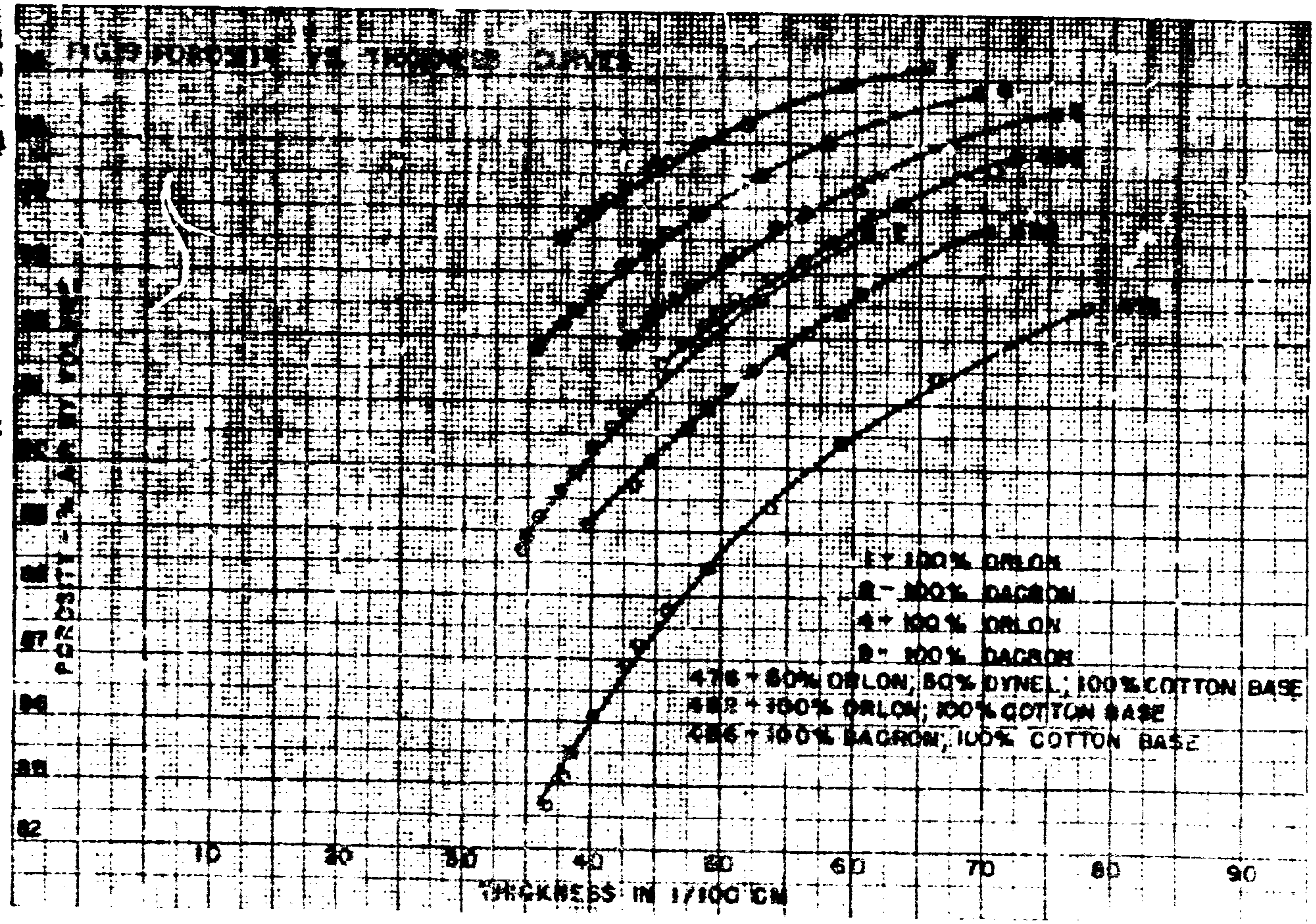


FIG 9 POROSITY VS THICKNESS CURVES
POROSITY - % AIR BY VOLUME
THICKNESS IN 1/100 CM
10
20
30
40
50
60
70
80
90
1 - 100% ORLON
2 - 100% DACRON
4 - 100% ORLON
5 - 100% DACRON
476 - 50% ORLON; 50% DYNEL; 100% COTTON BASE
482 - 100% ORLON; 100% COTTON BASE
486 - 100% DACRON; 100% COTTON BASE

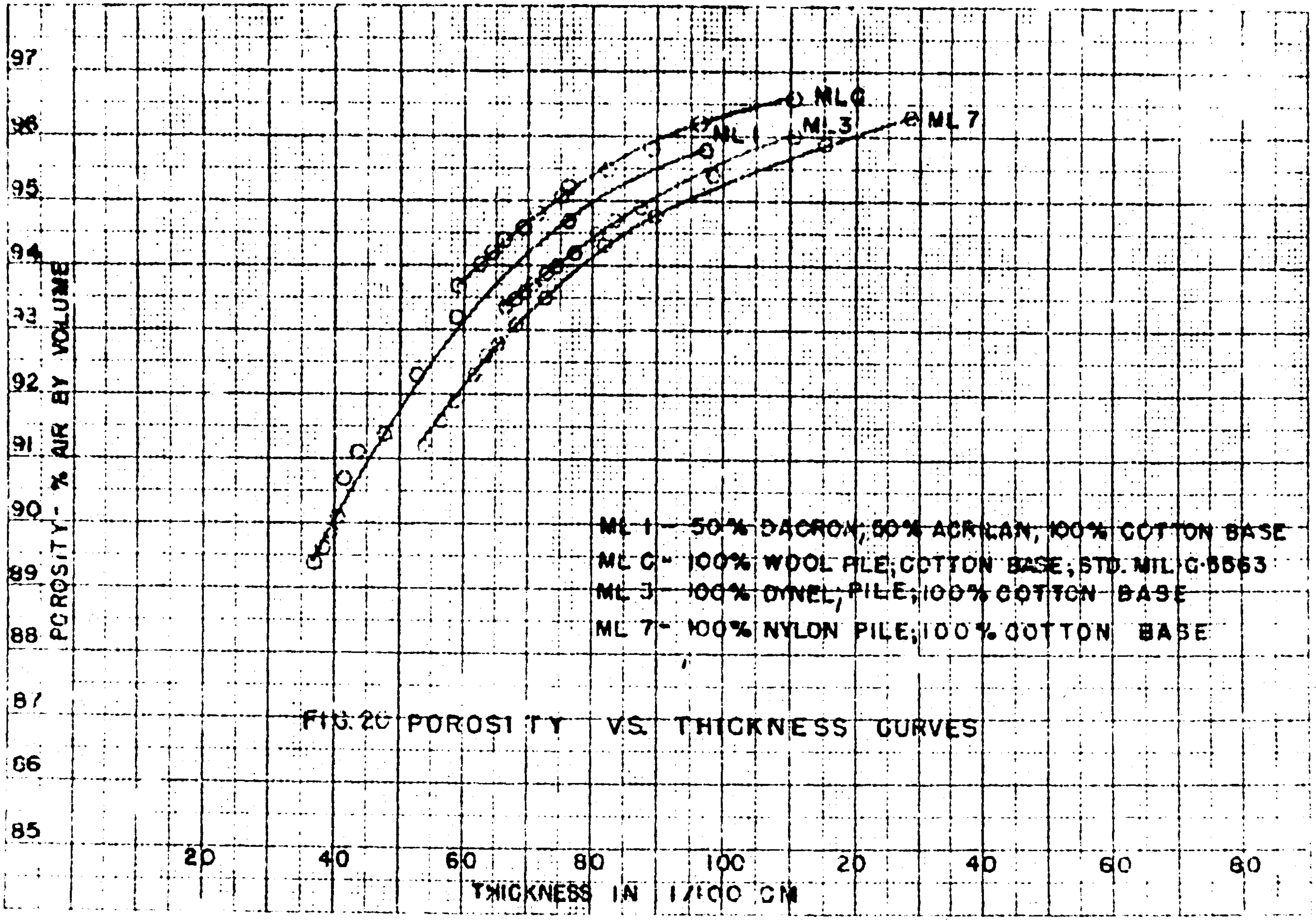


FIG. 20 POROSITY VS. THICKNESS CURVES

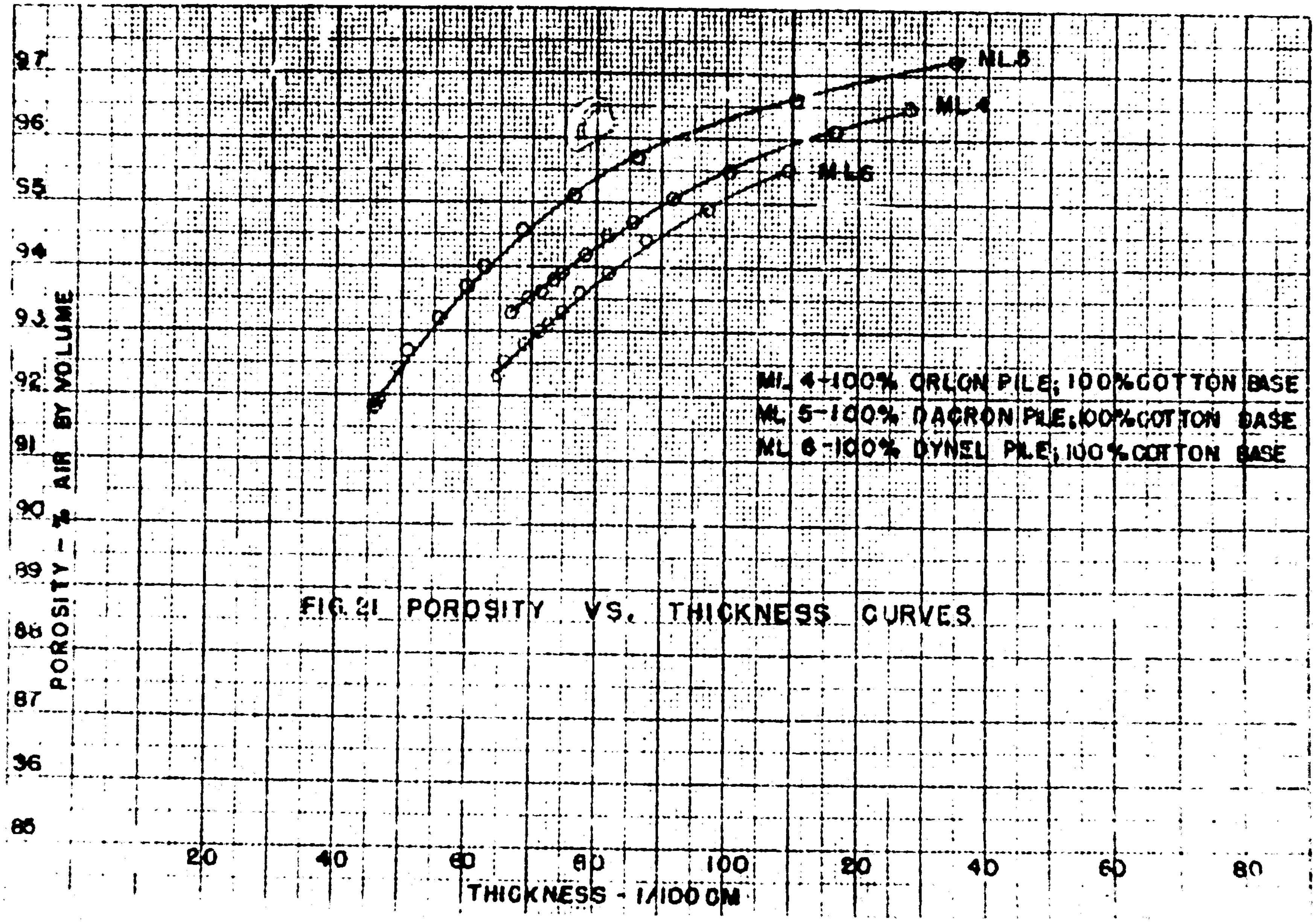


FIG. 21 POROSITY VS. THICKNESS CURVES

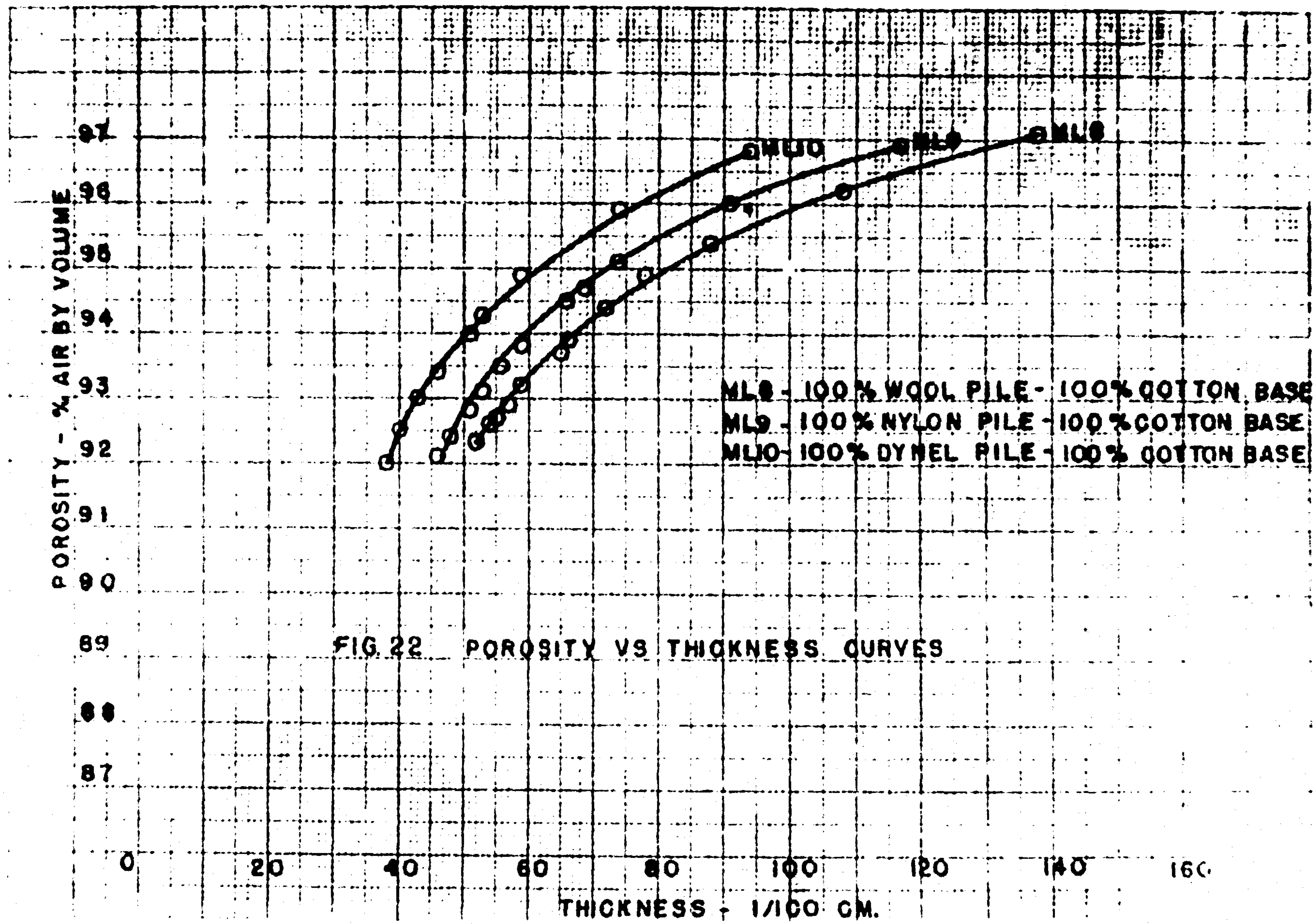


FIG. 22 POROSITY VS THICKNESS CURVES

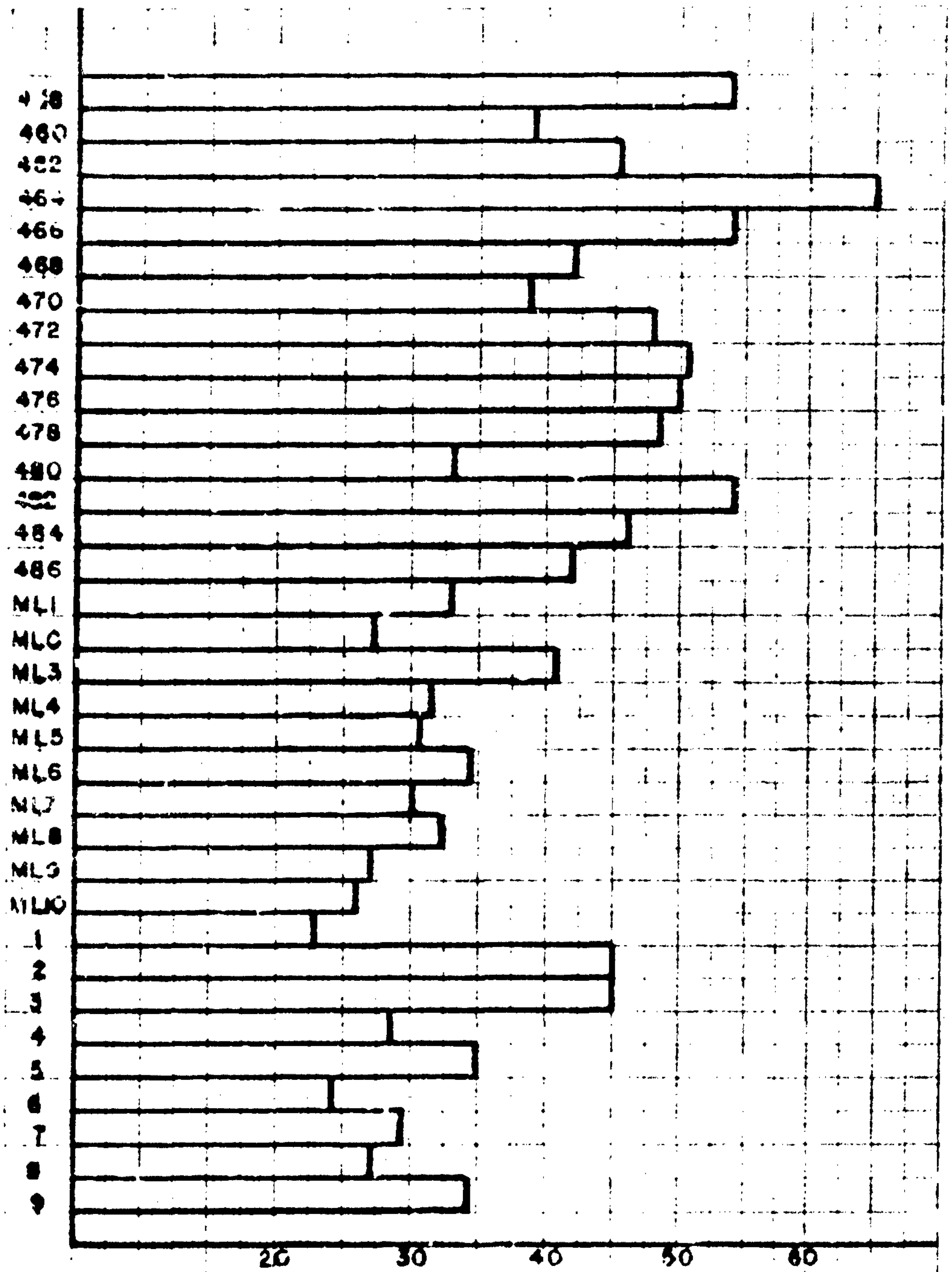


FIG. 23 WEIGHT TO WARMTH RATIO

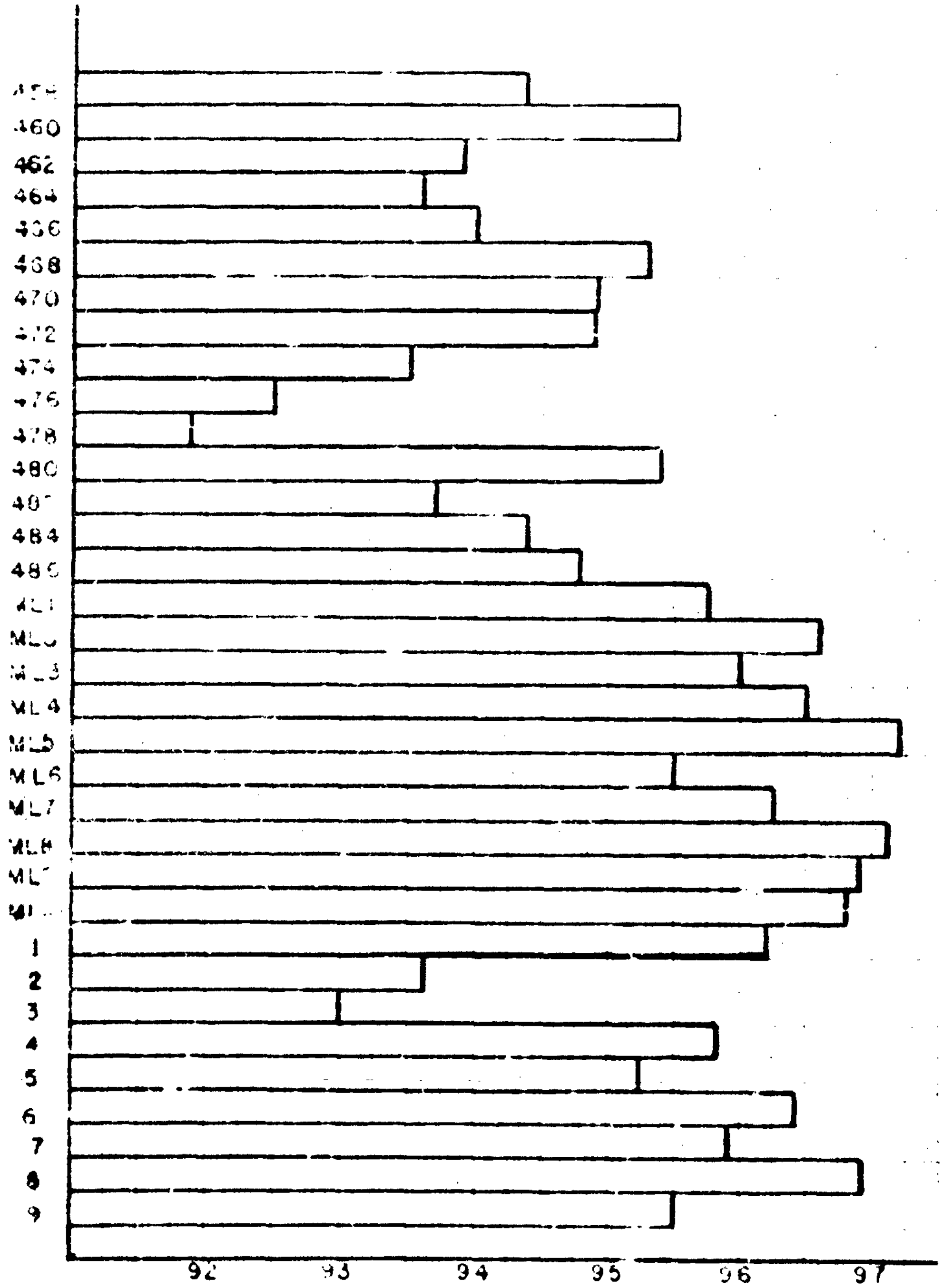


FIG. 24 POROSITY AT NO LOAD

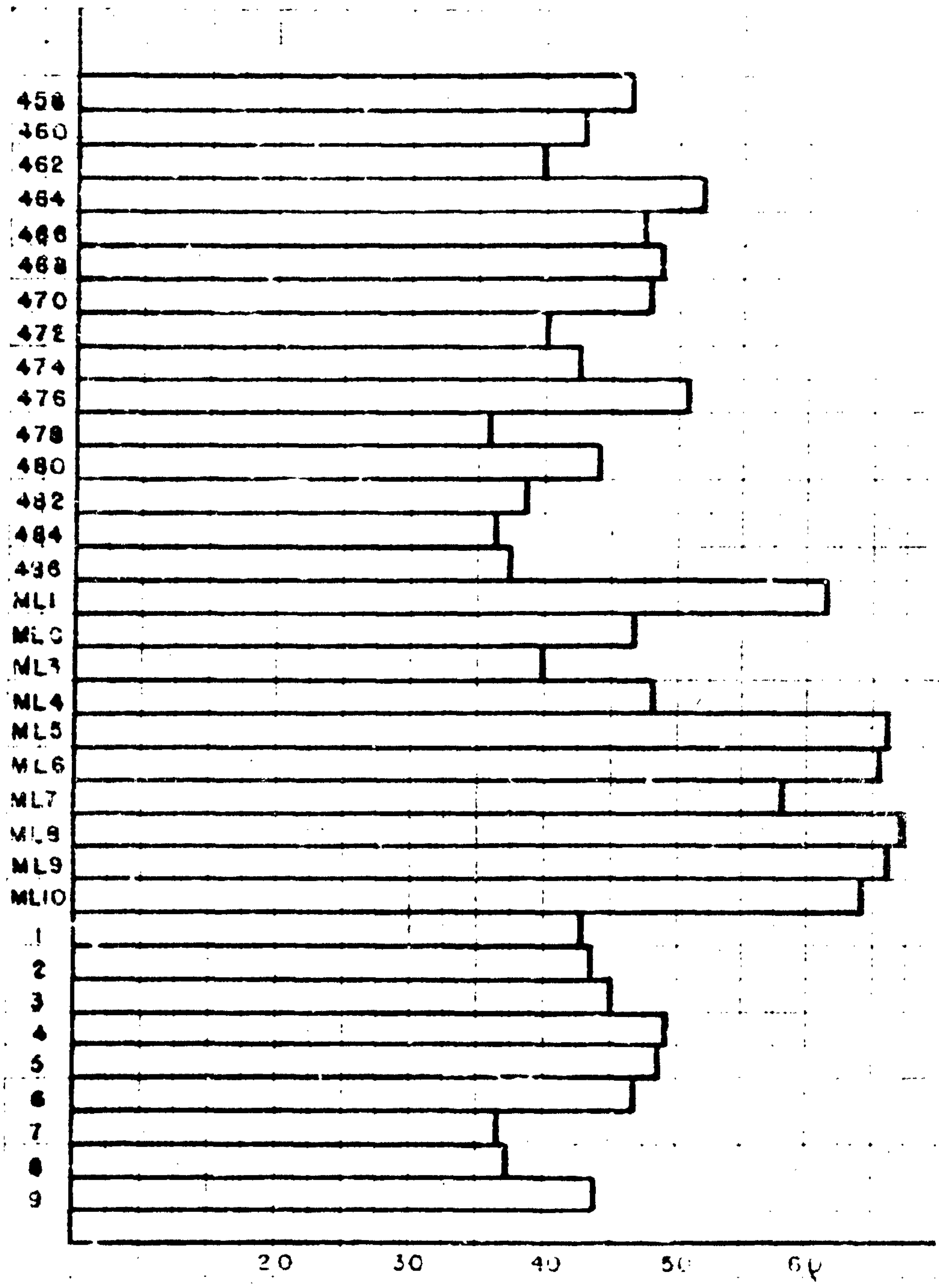


FIG 25 % COMPRESSIBILITY